Comparative Performance of Acoustic-Tagged and Passive Integrated Transponder-Tagged Juvenile Salmonids in the Columbia and Snake Rivers, 2007

A. Michelle Wargo Rub, Richard S. Brown,[†] Benjamin P. Sandford, Katherine A. Deters,[†] Lyle G. Gilbreath, Mark S. Myers, Mark E. Peterson, Ryan A. Harnish,[†] Eric W. Oldenburg,[†] Jessica A. Carter,[†] Ian W. Welch,[†] Geoffrey A. McMichael,[†] James W. Boyd,[†] Eric E. Hockersmith, and Gene M. Matthews

Report of research by

Fish Ecology Division, Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Blvd. East
Seattle, Washington 98112

and

[†]Ecology Group, Pacific Northwest National Laboratory
P.O. Box 999, MS K6-85
Richland, Washington 99352

for

Environmental Resources Branch, Planning and Engineering Division
Portland District, U.S. Army Corps of Engineers
Robert Duncan Plaza
333 S.W. 1st Avenue
Portland, Oregon 97208-2946
Contract W66QKZ60441152

November 2009

PREFACE

Telemetry technology has been used extensively to investigate patterns of fish migration, survival, and behavior (Winter 1996; Bridger and Booth 2003). In particular, both radio and acoustic telemetry have been useful to researchers because their generally high detection rates allow the use of small sample sizes. As the number of fish stocks listed under the U.S. Endangered Species Act has grown, efficient fish-marking tools such as acoustic and radio telemetry have become more important in studies of survival and behavior. In recent years, radio and acoustic transmitters have been miniaturized significantly, allowing their use in small fish such as juvenile salmonids.

Detection systems for radio and acoustic transmitters allow broad spatial coverage, and include both stationary and mobile receivers. Stationary acoustic receivers have been deployed in freshwater, estuarine, and ocean environments. Mobile tracking has been accomplished with vessels in both acoustic and radio telemetry studies and with vehicles and planes in radio studies. This flexibility in modes of coverage can provide greater detail on behavior and movement of individual animals than other forms of marking or tracking (Winter 1996).

Over the past 15 years, radiotelemetry has been used extensively in the Snake and Columbia Rivers to evaluate effects on fish behavior and survival of surface bypass collectors (Adams et al. 1996, 1997; Hensleigh et al. 1997) and turbines (Absolon et al. 2003). Evaluations of dam passage have utilized both acoustic (Anglea et al. 2001; Ploskey et al. 2001) and radio telemetry (Eppard et al. 1998, 2002, 2005a,b; Axel et al. 2003, 2004a,b; Hockersmith et al. 2005). However, to date the majority of these studies have been conducted on relatively small spatial scales, estimating survival past a single dam or through a limited reach of river. Evaluation of survival in a short reach or through a single dam has the advantage of minimizing potential bias from tag effects, which may develop over time or with distance from release.

This spatially restrictive approach was influenced by two radio telemetry studies conducted in the late 1990s. In the first of these, Hockersmith et al. (1999) evaluated the performance of surgically radio-tagged yearling Chinook salmon *Oncorhynchus tshawytscha* migrating over a distance of 238 km to Lower Granite Dam on the Snake River. Radio-tagged fish were compared to PIT-tagged cohorts released simultaneously from Lookingglass Hatchery on the Grande Ronde River. Results from this study indicated that the presence of a radio tag significantly affected growth, travel time, and survival compared to PIT-tagged fish. Radio-tagged fish passed Lower Granite Dam sooner, at a smaller size, and with lower survival rates than PIT-tagged fish. These researchers suggested that negative effects of the radio tag on fish performance may have exacerbated by the distance over which performance was measured.

In their follow-up study, Hockersmith et al. (2003) confirmed that regardless of tagging method (e.g. surgical or gastric), radio-tagged fish had lower survival than PIT-tagged fish over a migration distance of 225 km and with travel time greater than 10 d. However, survival and migration rates for radio-tagged fish were similar to those of PIT-tagged fish over 6 d or less and within a migration distance of 106 km. The tag-weight to body-weight ratio experienced by fish in this study ranged from 1.3 to 7.0%.

Based on these findings, a cautious approach in conducting and interpreting telemetry studies was warranted. However, the project-specific nature of past telemetry studies within the Columbia River Basin has made it difficult to extrapolate results from a single study site to a broader reach or to the run at large. Moreover, differing technologies (acoustic or radio) and methodologies among sites often prevented valid comparison of results from two or more locations.

To address these issues, the U.S. Army Corps of Engineers began development of a tagging system that would provide information on the migration and survival of juvenile fish through the hydropower system and into the estuary and ocean in a consistent and continuous manner. Additional goals of such a system were to promote data sharing among studies, reduce impacts on listed stocks, and improve efficiency in the use of public funds. The present study builds on work that was conceived and conducted to develop this single tagging system.

As a comprehensive tool for studying the life history of anadromous salmonids in the Columbia River Basin, acoustic telemetry may have several advantages over radiotelemetry. For example, radio signals attenuate quickly in saltwater and deep water, whereas acoustic signals are much less affected by these conditions (Winter 1996). In addition, unlike acoustic transmitters, radio transmitters generally require a trailing antenna, which may affect swimming performance, predator avoidance, and ultimately survival of tagged individuals (Adams et al. 1998; Brown et al. 1999; Murchie et al. 2004). In spite of these advantages, more information is needed to demonstrate that acoustic telemetry is sufficiently benign for use in juvenile salmonids.

One challenge in evaluation of acoustic tag effects is that the same statistical models developed to estimate survival using the PIT tag (single-release, multiple recapture models; Skalski et al. 1998) are used to estimate survival based on acoustic tag detections. As with PIT tag studies, assumptions associated with these models must be met if they are to produce unbiased estimates. Two such assumptions are: 1) individuals marked for the study are representative of the population of inference, and 2) all fish in a release group have equal probabilities of survival and detection (i.e., survival and capture probabilities are not affected by tagging or sampling; Skalski et al. 1998).

Despite progress in miniaturization of acoustic telemetry transmitters, meeting the first assumption has been difficult, since a portion of the juvenile Chinook salmon

Oncorhynchus tshawytscha population is smaller than the minimum size recommended for many tags. For example, in 2007 the overall population of subyearling Chinook salmon passing Lower Granite Dam ranged in size from 60 to 140 mm FL (Fish Passage Center). Yet most radio and acoustic tag studies have targeted smolts larger than this, using minimum fish sizes of 100 mm for smaller acoustic tags and 120 mm for larger radio tags. This caution has been practiced as an attempt to keep tag burdens to a minimum, and thus maintain validity of the second model assumption (Hockersmith et al. 2003; Ogden et al. 2005; Skalski et al. 2005).

The second model assumption requires that neither the presence of the tag nor the tagging procedure significantly affect fish performance. If the behavior of a smolt is altered by the tag, then application of survival estimates or passage timing using tagged smolts to the general (untagged) population would not be appropriate. For example, a tagged fish might swim at a different depth than a non-tagged fish, and therefore could be differentially susceptible to juvenile fish bypass systems, spillway passage, or surface bypasses. Marked fish may also be more susceptible to injury or predation (Maynard et al. 1996). Furthermore, surgical implantation requires more tagging and handling time than other tagging procedures (e.g., coded-wire or PIT-tag injection), and may result in higher rates of infection or other complications (Roberts et al. 1973; Lucas 1989; Kaseloo et al. 1992; Knights and Lasee 1996; Walsh et al. 2000).

In evaluations of potential tag effects, tag burden has been the most common metric used to predict whether or not a given implant will alter fish performance. Tag burden is most often described as the ratio of tag weight to fish weight (Anglea et al. 2004; Brown et al. 2006; Steig et al. 2004), although it is sometimes described as a function of length (Moore et al. 1990), both weight and length (Lacroix et al 2004), or weight in water (i.e. excess mass; Perry et al. 2001). Regardless of its definition, tag burden is employed to recognize and identify through practical measures, the potential effects that a given fish might experience due to the presence of the transmitter. These effects include increased metabolic requirements and altered swimming performance or behavior as the animal attempts to compensate for added weight and reduced space for buoyancy compensation (Perry et al. 2001).

Laboratory studies that utilized tag burden to examine the effects of acoustic transmitters on growth, survival, and swimming performance of juvenile salmonids have been conducted by Anglea et al. (2004), Brown et al. (2006), Moore et al. (1990), and Lacroix et al. (2004). Results from these studies have not been entirely consistent, and some focused on relatively large fish (>120 mm FL). Thus it is not clear whether the results of these studies can appropriately be projected onto smaller size classes of fish, where additional metrics may be critical in predicting tag effects (Jepsen et al. 2002).

Anglea et al. (2004) found no significant difference in critical swimming speed or susceptibility to predation in Chinook salmon tagged with an acoustic transmitter compared to non-tagged or sham tagged cohorts. Their acoustic tag weighed 1.5 g in air and represented 1.6-6.7% of fish body weight. Similar results were found by Brown et al. (2006) for Chinook salmon (94-125 mm) implanted with a 0.75-g acoustic transmitter representing 3.2-10.0% of fish body weight. However, Brown et al. (2006) found that growth rate decreased for acoustic-tagged Chinook salmon compared to control fish.

Moore et al. (1990) found no mortality within 150 d of surgery in juvenile Atlantic salmon *Salmo salar* (122-189 mm) implanted with acoustic transmitters with a mean tag burden of 2.2%. However by the end of the study, 20% of the implant group had dropped or expelled their acoustic tags. Growth between treatment groups was not found significantly different by Moore et al. (1990).

Lacroix et al. (2004) observed reduced swimming speeds in juvenile Atlantic Salmon at 1 and 3 d post surgery (mean tag burden 8.5%). In a companion experiment, they compared non-tagged juvenile Atlantic salmon with cohorts tagged with dummy acoustic transmitters. Significantly lower survival was found for fish implanted with dummy transmitters (136-165 mm; mean tag burden 8-10% by weight and 16-20% by length). Initially, Lacroix et al. (2004) also found the growth rate of fish with dummy implants was slower; however, by the end of the 316-d holding period, accelerated growth in the implanted fish made up for this size differential.

Field studies in general have reported favorable results. In the Columbia River, Skalski et al. (2003, 2005) observed similar survival rates from Wells and Rocky Reach Dams to Rock Island Dam between paired releases of acoustic and PIT-tagged yearling Chinook salmon. In their first study, acoustic tag burden ranged from approximately 2.7 to 4%, and median fish length for each replicate release group ranged from 156 to 211 mm (Skalski et al. 2003). In the second study, acoustic tag burden ranged from 1.3 to 4.6% (mean 2.5%; Skalski et al. 2004), and average fork length of release groups ranged from 110 to 225 mm (median 175 mm).

In 2006, Hockersmith et al. (2007a) conducted a pilot study to evaluate survival and behavior of yearling Chinook salmon tagged with the recently developed Juvenile Salmonid Acoustic Telemetry System (JSATS) acoustic transmitters (McComas et al. 2005). For the field experiments, migrating hatchery juvenile spring Chinook were collected and tagged with both a JSATS and PIT tag or with a PIT tag only (Hockersmith et al. 2007b). At the time, JSATS acoustic transmitters were approximately 40% smaller than the radio transmitters used by Hockersmith et al. (2003) and acoustic transmitters used by Skalski et al. (2003, 2005). For field evaluations, the acoustic tag burden ranged from 1.5 to 7.3% (mean 2.7%); tagged study fish size ranged from 105 to 240 mm FL (mean 137.2 mm) and from 10.5 to 50.1 g (mean 23.9 g).

Travel times for acoustic- and PIT-tagged fish were not significantly different from release to detection at Snake and Columbia River dams for the majority of downstream detection sites evaluated (Hockersmith et al. 2007b). Differences in PIT-tag detection probabilities between acoustic- and PIT-tagged fish at each downstream site were less than 2%. Similarly, Hockersmith et al. (2007b) found no significant difference in estimated survival between tag types from release to each detection site, with the exception of the first reach (Lower Granite to Little Goose Dam tailrace) where acoustic-tagged fish had higher survival than PIT-tagged fish. However, less than 3% of the 35,000 JSATS tags secured for this field study were available for fish migrating in spring 2006. Thus the weight of these results was seriously undermined by lack of replication and low sample sizes.

Concurrent laboratory studies were conducted in 2006 to evaluate potential effects of the JSATS tag on growth, mortality, tag loss, and predator avoidance in yearling and subyearling Chinook salmon (Brown et al. 2007a,b; Liedtke et al. 2007). Similar to the field study, laboratory results indicated no significant differences in survival among acoustic- and PIT-tagged hatchery yearling and subyearling Chinook salmon through the 90-d study period (Brown et al. 2007a). No significant differences were found in growth between acoustic- and PIT- tagged fish 21 or 90 d after tag implantation. The minimum fish length at which surgical implantation of a JSATS transmitter and a PIT tag did not negatively influence growth of juvenile Chinook salmon was 88 mm FL (Brown et al. 2007b). The minimum fish length at which surgical implantation of a JSATS transmitter and a PIT tag did not negatively influence survival was 95 mm FL (7.6% tag burden by weight). Predator avoidance was not significantly different between acoustic- and PIT-tagged subyearling Chinook, and there was no evidence of differential predation between study groups (Liedtke et al. 2007).

With preliminary results of the JSATS pilot study, and with an additional 8% reduction in tag size, in 2007 we continued both the field and laboratory work completed in 2006 by Hockersmith et al. (2007a). In spring and summer 2007, we compared the performance of yearling and subyearling Chinook salmon implanted with both a JSATS transmitter and a PIT tag to their respective cohorts implanted with only a PIT tag. Transmitters measured 15.8-17 mm long by 5.6-5.9 mm wide and 4.2-4.8 mm high depending on the vendor and tag model. Tags ranged in weight from 0.61 to 0.64 g in air (0.36-0.37 g in water), and tag volume ranged from 0.22 to 0.28 mL. For acoustic-tagged study fish in 2007, average sizes were 133 mm FL and 22.4 g for yearling Chinook, 107 mm and 12.8 g for subyearling Chinook, and 90.5 mm and 7.5 g for smaller subyearling Chinook (used for a pilot evaluation of smaller subyearlings). Tag burden by weight averaged 3.5% (range 1.5-8.9%) for yearling fish and 5.6% (range 1.9-12.5%) for subyearling fish.

During the field portion of the study, we compared survival and behavior of river-run Chinook salmon tagged with acoustic and PIT tags to that of their counterparts tagged only with a PIT tag. After tagging, fish from each treatment group were released to continue their migration, with subsamples targeted for recapture at strategic locations along the migration route. Subsampled fish were euthanized and examined for tag loss, disease, and histological changes due to tag implantation. Necropsy data from reference fish collected at the time of tagging was used to establish baseline fish condition.

A concurrent laboratory holding study was conducted using additional subsamples, which were taken from each release group at the time of tagging (fish were not allowed to continue migration). These fish were held for up to 90 d to observe tag loss, tissue response to tagging, long-term survival, and levels of *Renibacterium salmoninarum* (Rs), the agent responsible for bacteria kidney disease (BKD). Coded-wire tags were collected from fish throughout the season to assess whether relationships existed between variations in survival and individual hatchery release groups.

This report describes each separate evaluation and summarizes our conclusions to date based on the results. This information will aid in determining the suitability of acoustic telemetry to estimate short- and longer-term (up to 90 d) juvenile salmonid survival through Columbia and Snake River reservoirs and dams and through the Columbia River estuary. This information may also contribute to future research and development of acoustic technology.

CONTENTS

EVALUATION OF ACOUSTIC TAGS IN MIGRATING JUVENILE SALMON

Executive Summary

Yearling Chinook Salmon—Migration rates, detection and survival probabilities, and avian predation rates were compared between fish tagged with acoustic vs. passive integrated transponder (PIT) tags. During spring 2007, we collected migrating hatchery yearling Chinook salmon at Lower Granite Dam. We tagged 3,818 of these fish with both an acoustic and PIT tag (AT fish) and 46,714 with a PIT tag only (PIT-tagged fish). Samples were designed to be of sufficient size to determine a difference of 5% or more in survival from release to each detection location and to provide statistical power of 80% ($\alpha = 0.10$). Fish were released to the tailrace of Lower Granite Dam on 10 days from 24 April through 14 May.

Two slightly different acoustic tags were utilized: an earlier (2006) model, which weighed 0.64 g in air, and a later (2007) model, which weighed 0.60 g in air. Average tag burden experienced by AT fish was 3.5% of body weight. For both tag treatments, travel times, detection probabilities, and survival were estimated from individual PIT-tag detections at Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, and Bonneville Dams. For AT fish, we also utilized acoustic tag detections from multiple acoustic arrays for these estimates.

Mean detection probabilities were estimated for each detection site. Mean detection probability was higher for AT than PIT-tagged fish at Little Goose Dam, and the difference was significant ($P = 0.004$). However, PIT-tagged fish were significantly more likely to be detected at McNary and Bonneville Dams ($P = 0.018$ and 0.010, respectively). There were no significant differences in detection probabilities between tag groups at Lower Monumental, Ice Harbor, and John Day Dams ($P = 0.59$, 0.134, and 0.721, respectively).

In the Snake River, relative survival (ratio of estimates for AT/PIT-tagged fish) from release to Little Goose and Ice Harbor Dam was not significantly different from one ($P = 0.893$ and 0.285, respectively). However, relative survival to Lower Monumental Dam was 1.05, indicating survival was significantly higher at the 0.080 level for AT fish. In the Columbia River, relative survival was 0.92 ($P = 0.054$) to McNary Dam, 0.82 ($P = 0.010$) to John Day Dam, and 0.79 ($P = 0.001$) to Bonneville Dam. Significant differences in travel times between the two groups were observed only at John Day Dam ($P = 0.041$).

Overall mean PIT-tag recovery from upper river bird colonies was 0.9% for AT fish and 1.0% for PIT-tagged fish. From estuarine colonies, overall mean PIT-tag

recovery was 3.3% for AT fish and 2.7% for PIT-tagged fish. Recovery rates were not significantly different between tag treatments at either the upper river (P = 0.500) or estuarine bird colonies (P = 0.243).

Subyearling Chinook Salmon—In summer 2007, detection and survival probabilities, along with travel time and avian predation rates, were compared between AT and PIT-tagged subyearling Chinook salmon. For these evaluations, we tagged 9,833 river-run subyearling Chinook salmon with both an acoustic and a PIT tag (AT fish) and an additional 26,338 of these fish with a PIT tag only (PIT-tagged fish). Sample sizes were designed to obtain the same statistical accuracy as described above for yearling Chinook salmon.

For AT subyearlings, we separated evaluations for fish 95 mm FL or longer (AT fish) and smaller fish 85-94 mm (AT pilot fish). Mean tag burden was 5.6% (range 1.7-11.3) for AT fish and 9.6% (range 6.8-15.1%) for AT pilot fish. Fish were released to the tailrace of Lower Granite Dam on 27 days from 4 June to 13 July. Late model (2007) acoustic transmitters weighing 0.61 g in air were used exclusively for subyearling evaluations.

Mean probabilities of detection and survival for AT and PIT-tagged fish were estimated from release at Lower Granite to detection at Little Goose and McNary Dam. We were unable to calculate reliable estimates of detection or survival at any other downstream locations due to low detection numbers of both tag treatments. For AT pilot fish, detections were too few for meaningful analyses of detection probability or survival at any downstream location.

Mean detection probability was greater for AT than PIT-tagged fish at Little Goose Dam, and the difference was significant (P = 0.001). There was no significant difference in mean detection probability between groups at McNary Dam (P = 0.505). Mean survival from Lower Granite to Little Goose Dam was significantly higher for PIT than AT fish (P = 0.003), as was survival to McNary Dam (P = 0.001). Fish belonging to the AT group took significantly more time than PIT-tagged fish to travel from Lower Granite to Little Goose (P = 0.000), Lower Monumental (P = 0.009), Ice Harbor (P = 0.036), and McNary Dams (P = 0.002).

Due to a combination of low survival to the estuary and low numbers of PIT-tag recoveries from subyearling Chinook released on or after 30 June, we were unable to make reliable comparisons of avian predation for these fish. For subyearlings released from 4 to 30 June, overall mean PIT-tag recovery from upriver bird colonies was 1.3% for AT fish and 1.7% for PIT-tagged fish. The difference between the two groups was not significant (P = 0.254). For fish released before 30 June, PIT-tag recovery from estuarine sites was 2.5% for AT fish and 2.0% for PIT-tagged fish, and the difference was not significant (P = 0.389).

Introduction

We compared survival and behavior of migrating Chinook salmon implanted with both an acoustic transmitter and passive integrated transponder (PIT) tag to those with a PIT tag only. During spring and summer 2007, river-run yearling and subyearling Chinook were collected, tagged, and released at Lower Granite Dam. Detections of study fish were obtained from downstream dams equipped with PIT-tag monitors (Figure 1) and from a trawl detection system operated in the upper Columbia River estuary (rkm 61-83). Detections from acoustic transmitters were obtained from receiver arrays in the Columbia River and estuary (Appendix Tables A1 and D1). In addition, we compared the percentage of PIT tags recovered from piscivorous waterbird colonies to determine if one tag treatment group was more vulnerable to avian predation than the other.

The study area included a 695-km reach of river from Lower Granite Dam on the lower Snake River to the mouth of the Columbia River (Figure 1). Lower Granite Dam is the fourth dam upstream from the mouth of the Snake River and is located in Washington State, 173 km above the confluence of the Snake and Columbia Rivers.

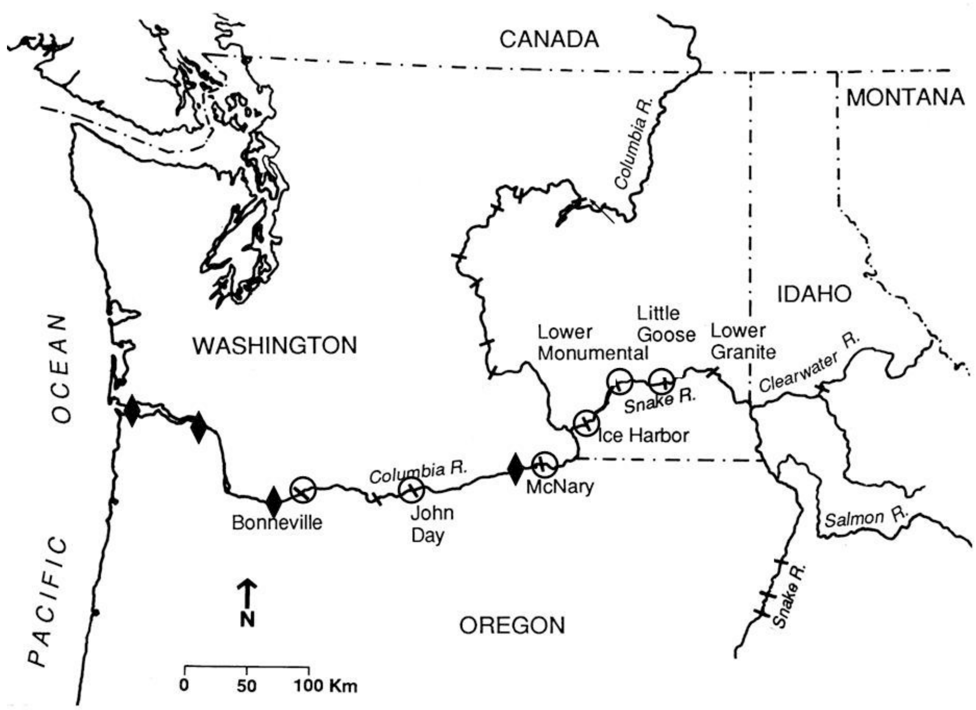


Figure 1. Study area showing release location at Lower Granite Dam and downstream detection sites. Diamonds indicate the locations of acoustic arrays (Appendix Table A1) and circles show locations of PIT-tag monitors (Appendix Table D1).

In the Snake River, discharge at Lower Granite Dam was below the 10-year average during most of the 2007 study periods for both yearling (24 Apr-9 Jul) and subyearling Chinook salmon (5 Jun-7 Sep; Figure 2). In the Columbia River, discharge at McNary Dam was higher than the 10-year average during most of the yearling study, but lower than the 10-year average during much of the subyearling study (Figure 2).

Water temperatures in the Snake and Columbia Rivers during both the yearling and subyearling study periods were similar to the 10-year average (Figure 2). At Lower Granite Dam, water temperature varied throughout both study periods, while at McNary Dam, temperature increased linearly from April through July. In early August, water temperature at McNary Dam peaked at approximately 21°C and remained above 18°C through the end of September.

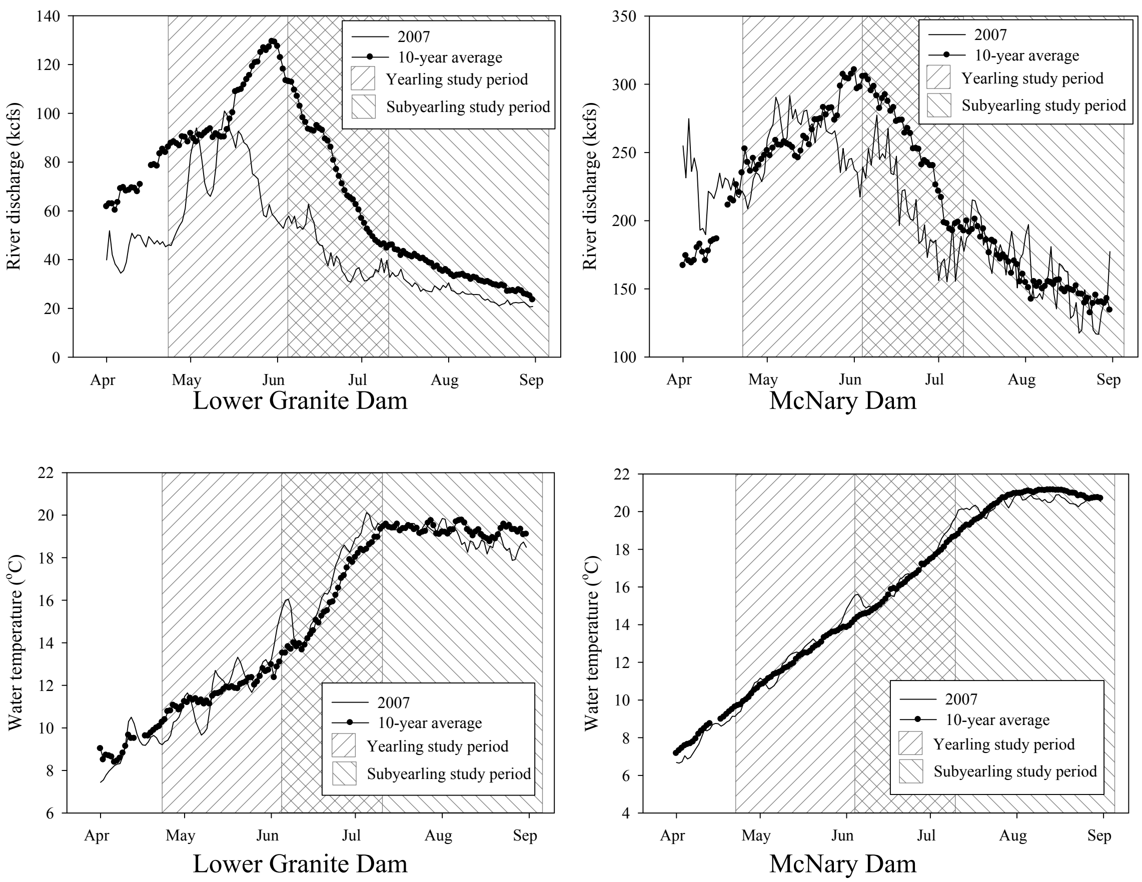


Figure 2. Upper charts show discharge at Lower Granite and McNary Dam during the study period in 2007 compared to the 10-year average (1997-2006). Lower charts show water temperature at Lower Granite and McNary Dams compared to the 10-year average (1997-2006).

Methods

Fish Collection, Tagging, and Release

Yearling Chinook Salmon—River-run, hatchery yearling Chinook salmon smolts were collected from the run at large at Lower Granite Dam between 21 April and 13 May. Between 1900 and 0700 PDT on these dates, study fish were diverted to a concrete raceway for holding. Within 12-18 h of collection, fish were sorted under light anesthesia using clove oil as an induction agent followed by tricaine methanesulfonate (MS-222; Marsh et al. 1996, 2001).

We tagged only hatchery yearling Chinook that had not been previously PIT tagged, had no visual signs of disease or injury, and measured at least 95 mm FL. Fish selected for PIT-tagging only (PIT-tagged fish) were tagged immediately following sorting. Collection and handling techniques followed the methods described in Marsh et al. (1996, 2001). Fish were measured and injected with PIT tags using a method similar to that of Prentice et al. (1990a,b). To reduce the likelihood of disease transmission, all needles and PIT tags were disinfected in 70% ethyl alcohol for a minimum of 10 minutes prior to use.

Fish selected for acoustic tagging (AT fish) were collected in 20-L plastic buckets directly after sorting and transferred to a 75-L holding tank where they were allowed to recover from the anesthetic. Fish were then held overnight in flow-through river water prior to tagging. As such, AT fish were held for 18-24 h longer than PIT-tagged only fish.

Prior to surgery, AT fish were placed in an anesthetic bath containing MS-222 in concentrations ranging from 50 to 80 mg/L until they reached stage 4 anesthesia (loss of equilibrium; Summerfelt and Smith 1990). Temperature and pH of the anesthetic bath was monitored several times daily to ensure that temperature did not increase more than 2°C during a tagging session and that pH did not drop below 7.0. Frequent water/anesthetic changes and the addition of sodium bicarbonate as a buffering agent were used to maintain these conditions. After reaching stage 4 anesthesia, fish were removed from the anesthetic bath and transferred in 1-L plastic cups to a data station where they were weighed and measured.

After pre-processing, fish were placed on a surgery table ventral side up and administered either additional anesthesia or river water over the gills. Either MS-222 (50 mg/L), pure river water, or a combination of both were delivered through gravity-fed rubber tubing. The decision to administer additional anesthetic or to perform surgery while administering pure river water was left to the individual surgeon and based on achieving a balance between maintaining a level plane of stage 4 anesthesia throughout the surgical process and allowing for rapid post-operative recovery.

Surgical tagging was conducted simultaneously at up to four stations, with approximately 75-100 acoustic tags implanted per hour. All surgical tools were sterilized in a steam autoclave prior to the start of each tagging day. All acoustic transmitters and PIT tags were disinfected in 70% ethyl alcohol for a minimum of 10 min and rinsed in distilled water prior to use. Suture material and surgical tools were disinfected and rinsed in the same manner between consecutive surgeries.

Once the desired level of anesthesia was reached, a 6-8 mm incision was made 2-5 mm from and parallel to the mid-ventral line (linea alba) just anterior of the pelvic girdle of each fish. Incisions were made using either a 3.0-mm Micro-Unitome blade[1] (BD Medical Supplies), a number 10 scalpel blade, or a combination of both. First a PIT tag and then an acoustic transmitter was inserted into the peritoneal cavity through the incision. Following tag insertion, each incision was closed with two 5-0 absorbable monofilament sutures placed in a simple interrupted pattern.

Immediately following tagging, AT fish were placed into 75-L oxygenated containers and held for a minimum of 2 h for anesthetic recovery and to observe for post-tagging mortality. Implanted fish were then transferred water-to-water to an 18,500-L holding tank supplied with flow-through river water and commingled with PIT fish that had been tagged on the same day.

Following a post-tagging recovery period of 12-24 h, AT and PIT-tagged fish tagged on the same day were released simultaneously into the tailrace of Lower Granite Dam. Fish were released by connecting their common holding tank to the juvenile bypass system outfall pipe with a 10.2-cm diameter flexible hose. All fish tagged and released for this study were assigned a "no transport" designation in the PTAGIS system. This classification ensured that our study fish would not be placed on barges if they were collected at downstream dams. Yearling Chinook salmon belonging to the PIT-tagged fish group served a dual purpose as both reference fish for our comparisons to acoustic-tagged fish and as "inriver migrants" for a latent mortality study (BPA Project 2003-041-00).

A total of 3,818 AT fish and 46,714 PIT-tagged fish were released to the tailrace of Lower Granite Damon on 12 release days (Table 1). Sample sizes were chosen to estimate a 5% difference in survival from release to each detection location downstream with 80% power, and at a significance level of $\alpha = 0.10$. The first release on 25 April coincided with detection of the 20th percentile of the cumulative smolt index for yearling Chinook salmon passing Lower Granite Dam in 2007, and the final release on 15 May coincided with the 93rd percentile (Figure 3).

[1] Use of trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 1. Number and mean fork length of AT and PIT-tagged fish released at Lower Granite Dam in 2007.

	Yearling Chinook salmon					
	AT fish			PIT-tagged fish		
Release date	N	Fork length (mm)	SD	N	Fork length (mm)	SD
24 April	0	-	-	4,512	133.8	13.2
25 April	404	130.7	11.6	0	-	-
26 April	397	131.4	11.1	3,769	129.6	11.2
28 April	404	133.4	11.5	3,334	129.3	11.9
1 May	403	130.9	10.4	3,792	132.2	10.0
3 May	406	132.7	10.3	8,040	132.0	10.7
5 May	412	135.0	8.1	5,579	135.0	10.0
8 May	0	-	-	3,561	133.9	9.7
9 May	414	133.4	9.7	0	-	-
10 May	299	135.6	7.8	4,773	134.1	9.4
12 May	311	133.7	8.6	4,804	135.1	8.3
15 May	368	133.8	8.3	4,550	135.0	9.1
Total	3,818	133.0	9.9	46,714	133.2	10.6

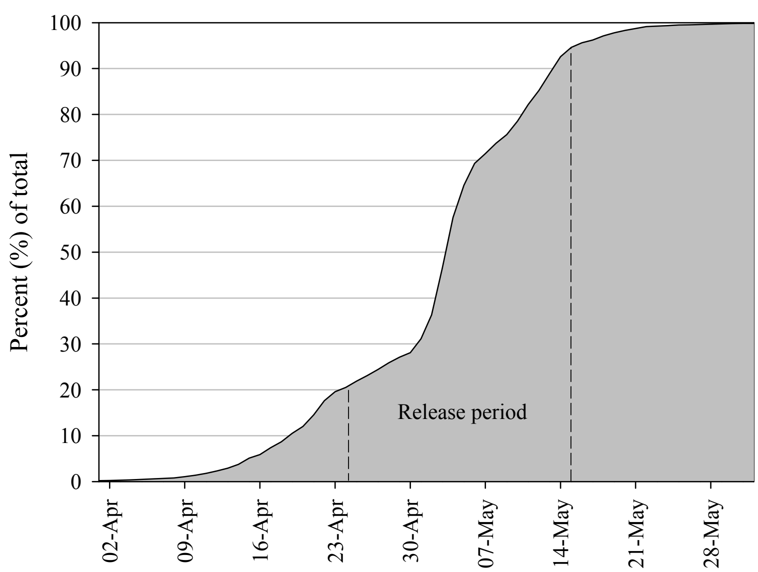


Figure 3. Cumulative passage distribution of yearling Chinook salmon at Lower Granite Dam in 2007.

Acoustic-tagged fish had a mean fork length of 133 mm, mean weight of 22.4 g, and experienced a mean tag burden of 3.5% from the combined presence of the acoustic transmitter and PIT tag. Mean tag burden from the acoustic tag alone was 2.9%. For, PIT-tagged fish, mean fork length was 133 mm. Weights were not obtained for fish tagged with a PIT-tag only. Fork lengths of both AT and PIT-tagged fish were representative of the general population of river-run yearling Chinook salmon sampled by the smolt monitoring program (SMP) during the study period. Mean fork lengths among study fish and SMP sample fish were similar on most release days (Figures 4 and 5).

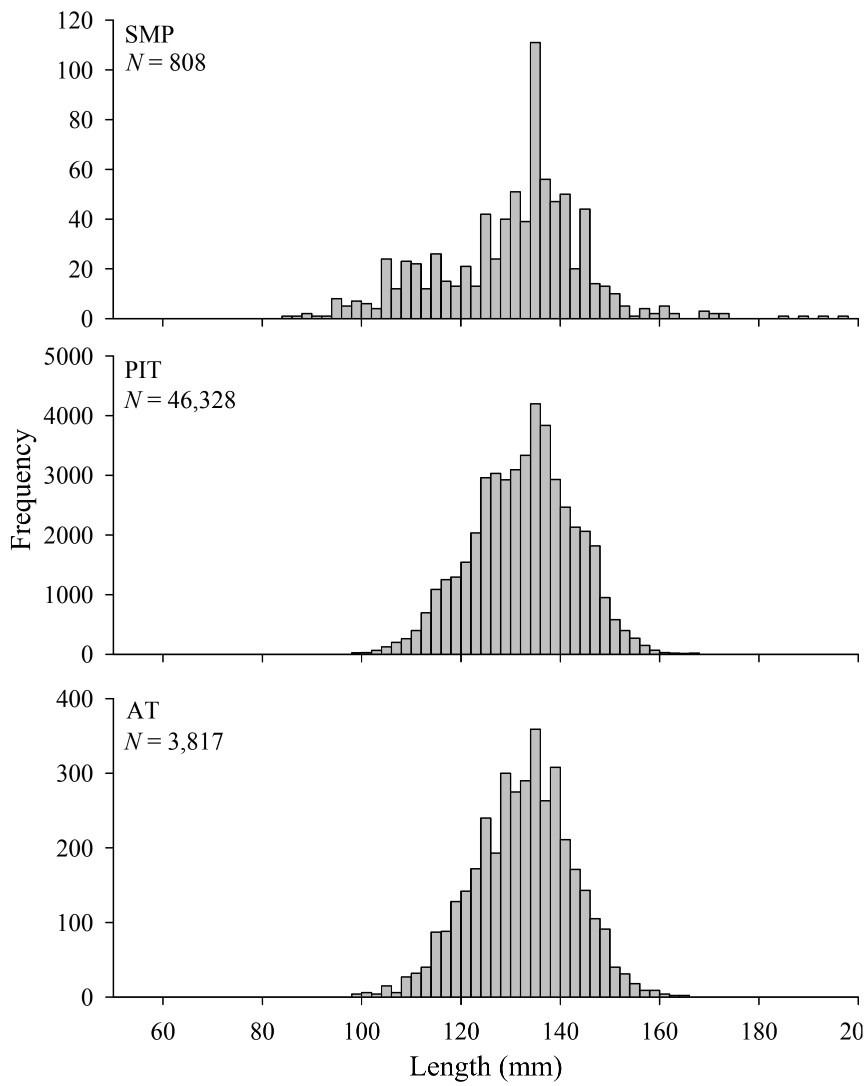


Figure 4. Length frequency histograms (2-mm bins) comparing fork lengths of yearling Chinook salmon sampled by the smolt monitoring program (SMP) to AT and PIT yearling Chinook salmon released at Lower Granite Dam in 2007. Smolt monitoring program data provided by the Fish Passage Center.

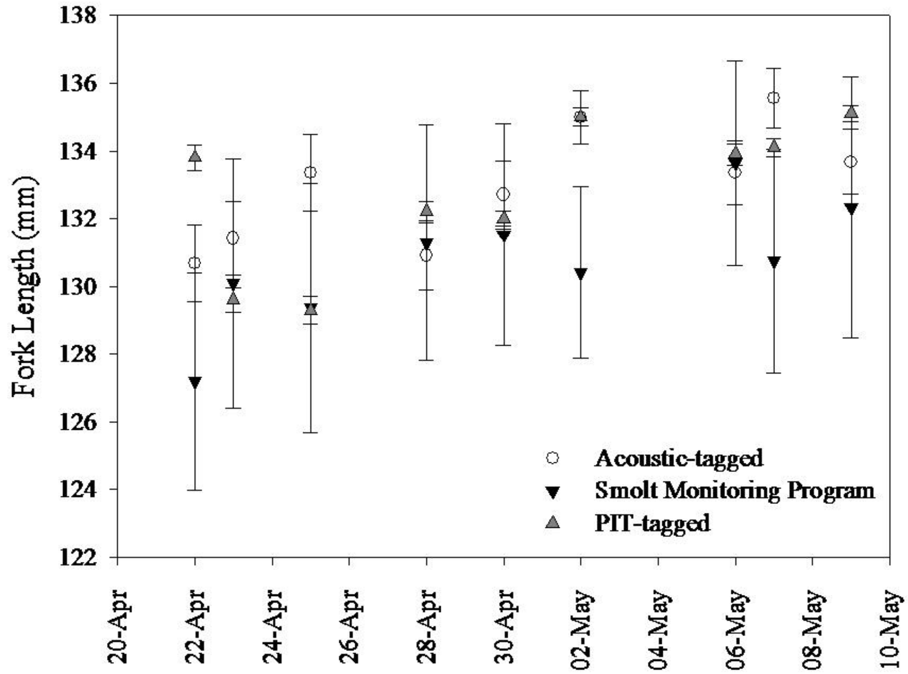


Figure 5. Mean fork lengths (whiskers represent 95% confidence intervals) of AT and PIT yearling Chinook salmon and yearling Chinook salmon sampled by the SMP at Lower Granite Dam in 2007. SMP data provided by the Fish Passage Center.

Individual PIT-tag detections at Little Goose, Lower Monumental, McNary, John Day, and Bonneville Dams were utilized to estimate travel time and detection and survival probabilities for PIT-tagged fish. A few study fish were also detected with the NMFS trawl detection system operated in the upper estuary (rkm 61-83). To estimate detection probabilities for AT fish, we used PIT-tag detections at these sites, along with acoustic detections from arrays near Irrigon, Oregon, downstream from Bonneville Dam, and in the lower Columbia River and estuary (Figure 1; Appendix Tables A1 and D1). Travel times and avian predation rates for AT fish were based solely on PIT-tag detections.

Acoustic-tagged fish were implanted with Juvenile Salmonid Acoustic Telemetry System (JSATS) transmitters. Two JSATS transmitter models were used for yearling fish (either 2006 or 2007), and both models were manufactured by Sonic Concepts (Table 2). Each acoustic tag transmitted a uniquely coded 31-bit binary phase-shift keyed signal at a frequency of 416.7 kHz and at a minimum source level of 150 dB (relative to 1 μPascal at 1 minute). The pulse rate interval was 10 seconds, and minimum tag life was 55 d. Tags were activated 1-2 d prior to tagging by a small solder connection, which was then sealed by UV-activated epoxy. Dimensions of the two JSATS acoustic tag models are shown in Table 2, along with dimensions of the TX-1400ST (ST) PIT tag.

Table 2. Specifications of the 2006 and 2007 JSATS acoustic tag and TX-1400ST (ST) PIT tags used in tag comparison study of yearling Chinook salmon, 2007.

	JSATS Acoustic tags (SD)		
	2006	2007	ST PIT tag (SD)
Length (mm)	17.0 (0.2)	16.1 (0.2)	12.48 (0.1)
Height (mm)	4.8 (0.2)	4.1 (0.1)	
Width (mm)	5.9 (0.1)	5.9 (0.1)	
Weight in air (g)	0.64 (0.001)	0.6 (0.007)	0.1020 (0.0010)
Mean mass in water (g)	0.36 (0.007)	0.38 (0.005)	
Mean volume (mL)	0.28	0.24	
Diameter (mm)			2.07 (0.02)
Mean tag burden (% body)	2.9 (range 1.3-7.7)		0.5 (range 0.2-1.2)

Subyearling Chinook Salmon—River-run hatchery and wild subyearling Chinook salmon were collected from the smolt collection facility at Lower Granite Dam from 2 June to 12 July 2007. Study fish were collected, handled, and tagged in a manner similar to that described above for yearling Chinook salmon, with one exception. Acoustic-tagged subyearling fish were allocated to two AT size groups based on length at tagging. The main test group (AT fish) consisted of subyearling fish that were 95 mm FL or longer. A second pilot group (AT pilot fish) consisted of fish that measured 85-94 mm FL. All PIT-tagged fish measured at least 82 mm FL.

Totals of 7,736 AT fish, 2,097 AT pilot fish, and 26,338 PIT-tagged fish were released to the tailrace of Lower Granite Dam (Table 3). Similar to the yearling portion the study, sample sizes were chosen to estimate a 5% difference in survival from release to each detection location downstream with 80% power, and at a significance level of $\alpha = 0.10$. The first release on 5 June coincided with detection of the 26th percentile of the cumulative smolt index for subyearling Chinook salmon passing Lower Granite Dam in 2007, and the final release on 14 July coincided with the 91st percentile (Figure 6).

Acoustic-tagged fish had a mean fork length of 107 mm, mean mass of 12.8 g, and experienced a mean tag burden of 5.6% from the combined presence of the acoustic transmitter and PIT tag. Mean tag burden from the PIT tag alone was 0.9% (range 0.3-1.7%). The AT pilot fish had a mean fork length of 91 mm, mean weight of 7.5 g, and experienced a mean tag burden of 9.6% from the combined presence of the acoustic transmitter and PIT tag. Mean tag burden from the presence of the PIT tag alone was 1.5%. For PIT-tagged fish, mean fork length was 108 mm, mean weight was 13.8 g, and mean tag burden was 0.7%.

Table 3. Number and mean fork length of AT pilot, AT, and PIT subyearling Chinook salmon released at Lower Granite Dam in 2007.

	Subyearling Chinook salmon								
	AT pilot (85-94 mm)			AT (≥95 mm)			PIT-tag		
Release date	N	Fork length (mm)	SD	N	Fork length (mm)	SD	N	Fork length (mm)	SD
5 June	90	88.9	2.3	260	105.3	6.7	1,096	106.0	6.5
6 June	87	89.9	2.7	267	104.1	5.9	1,171	105.1	6.5
7 June	91	89.0	2.6	263	103.7	5.6	1,131	104.6	6.4
8 June	89	88.9	2.7	263	103.7	5.0	1,081	105.7	5.5
9 June	81	89.6	2.9	271	103.8	5.2	1,133	106.9	6.0
12 June	89	91.3	2.5	261	104.6	5.4	1,070	105.6	5.6
13 June	92	90.9	2.5	270	103.6	5.7	1,143	106.4	6.4
14 June	113	90.8	2.7	308	103.4	5.9	1,075	107.0	6.9
15 June	103	90.7	2.6	323	103.0	5.7	895	107.5	6.9
16 June	127	89.9	2.5	270	101.6	5.2	1,240	107.4	6.1
19 June	104	90.8	2.5	328	108.5	7.6	1,225	109.0	7.8
20 June	106	90.5	2.4	247	105.1	6.4	906	109.2	7.6
21 June	97	91.2	2.6	273	105.7	6.6	834	109.5	7.9
22 June	89	91.0	2.3	320	106.1	6.9	759	109.4	8.1
23 June	108	90.8	2.5	302	106.7	7.4	1,002	111.0	7.2
26 June	79	90.5	2.5	337	107.8	6.9	1,412	108.9	7.0
27 June	98	90.6	2.8	246	106.5	6.2	1,154	108.7	6.8
28 June	116	90.8	2.7	270	106.0	5.6	973	108.5	7.0
29 June	71	90.5	2.5	243	106.7	6.3	386	109.1	7.4
30 June	59	91.2	2.8	290	106.6	6.5	616	110.4	7.0
3 July	40	90.4	2.2	271	110.7	7.5	1,089	109.7	8.2
4 July	84	91.0	2.6	292	108.6	8.1	649	111.3	8.1
5 July	53	91.7	2.4	237	107.3	8.2	605	111.2	8.5
6 July	4	89.8	3.4	137	109.6	7.7	1,448	111.5	7.5
11 July	0	-	-	0	-	-	274	111.1	8.5
12 July	2	94.0	0.1	549	111.3	8.6	771	111.2	8.7
13 July	13	91.5	2.4	329	113.6	10.0	433	110.4	8.3
14 July	12	92.1	2.3	309	111.1	8.6	767	111.8	8.9
Total	2,097	90.5	2.7	7,736	106.6	7.6	26,338	108.4	7.5

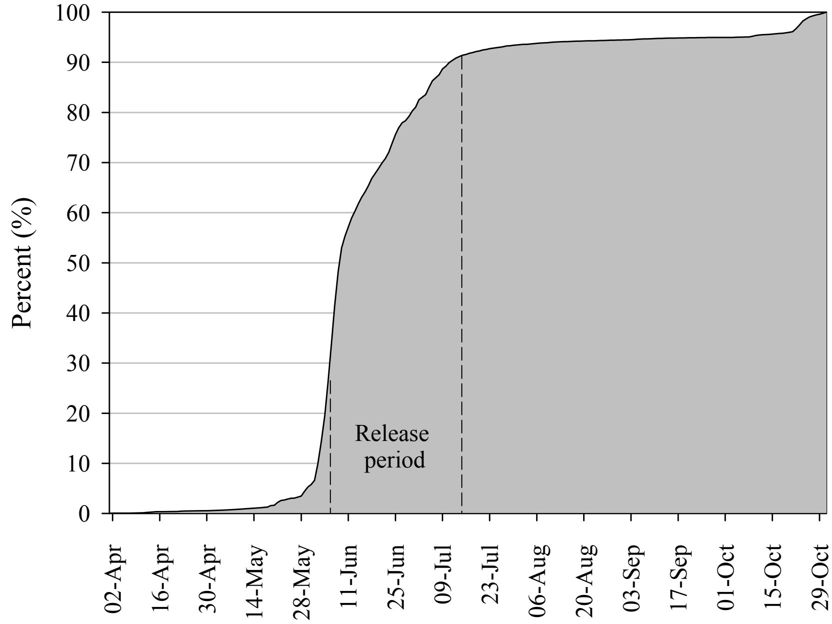


Figure 6. Cumulative passage distribution of subyearling Chinook salmon at Lower Granite Dam in 2007.

Size-frequency distributions of AT and PIT-tagged subyearling fish were similar to those of the run at large based on SMP samples (Figure 7). Mean fork length was similar among the PIT-tagged fish, the AT fish, and the SMP sample fish on most release days (Figure 8). Mean fork length of AT Pilot fish was less than that of SMP sample fish on every release day (Figure 8); however, there was still a component of the SMP sample fish that was smaller than the AT pilot fish.

Similar to estimates for yearling Chinook¸ we used PIT-tag detections at Little Goose, Lower Monumental, McNary, John Day, and Bonneville Dam to estimate travel times, detection probabilities and survival for PIT-tagged fish. Detections from the trawl system operated in the estuary (rkm 61-83) were also used for these estimates. To estimate detection probabilities for AT fish, we used PIT-tag detections from the same sites, along with acoustic detections from Irrigon, Bonneville, and the lower river and estuary. Travel times and avian predation rates for AT fish were based solely on PIT-tag detections.

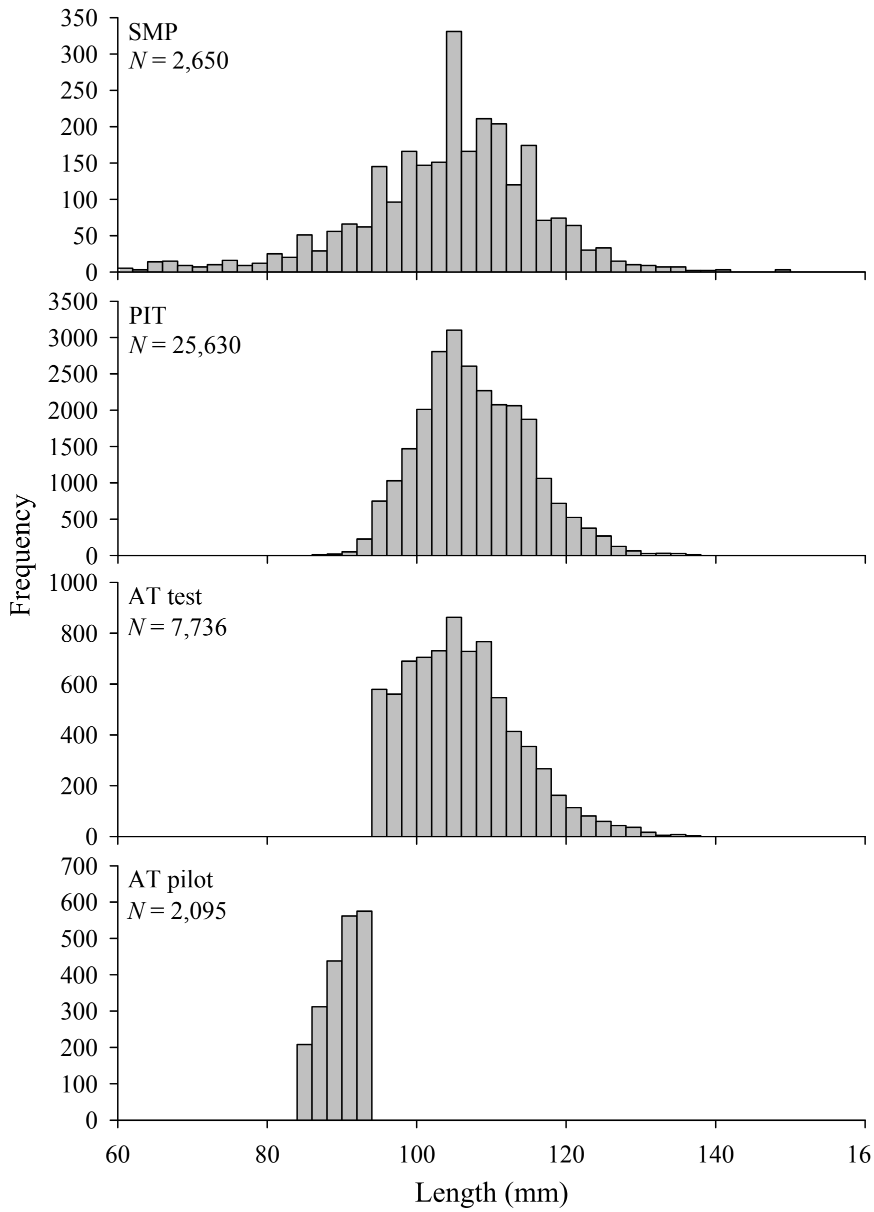


Figure 7. Length frequency histograms (2-mm bins) comparing fork lengths of subyearling Chinook salmon from the SMP sample to AT, AT pilot, and PIT-tagged fish released at Lower Granite Dam in 2007. Smolt Monitoring Program data provided by the Fish Passage Center.

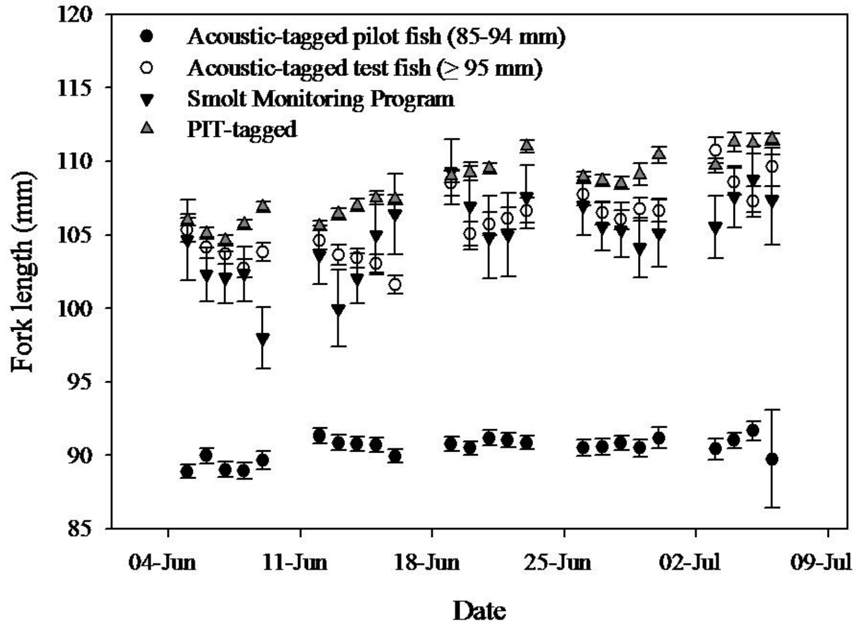


Figure 8. Mean fork lengths (whiskers represent 95% confidence intervals) of AT pilot, AT, and PIT subyearling Chinook salmon compared to those sampled by the SMP at Lower Granite Dam in 2007. SMP data were provided by the Fish Passage Center.

Subyearling Chinook salmon were implanted with JSATS acoustic transmitter tags manufactured by Advanced Telemetry Systems, Inc. Average dimension of the tags (± SD) are shown in Table 4, with dimension of PIT-tags for comparison. The pulse rate interval was 5 seconds, while other aspects of the tag signal were similar to those described above for JSATS transmitters implanted in yearling Chinook salmon. Tags were activated 1-2 d prior to tagging by placement in an electromagnetic activation dish.

Table 4. Dimensions of the 2007 JSATS acoustic tag and TX-1411SST (SST) PIT tags are shown below.

	2007 JSATS tag (SD)	SST PIT tag (SD)
Length (mm)	15.8 (0.2)	12.48 (0.1)
Height (mm)	4.2 (0.2)	
Width (mm)	5.6 (0.2)	
Weight in air (g)	0.61 (0.01)	0.1020 (0.0010)
Mean mass in water (g)	0.37 (0.004)	
Mean volume (mL)	0.22	
Diameter (mm)		2.07 (0.02)
Mean tag burden (% body wt)	5.6 (range 1.7-11.3)	0.9 (range 0.2-1.2)

Detection and Survival Estimates

Survival and detection probability estimates for both AT and PIT-tagged fish were evaluated using the Cormack-Jolly-Seber (CJS) model (Cormack 1964; Jolly 1965; Seber 1965). To estimate survival at a given location, the model requires a detection probability estimate for that location. In turn, to estimate detection probability at a given location, subsequent detection at a point downstream from that location is required. Thus survival and detection probability estimates require detection data from at least one additional location downstream from the point of interest.

The CJS model was implemented using Survival with Proportional Hazards (SURPH) software (Smith et al. 1994). Detection history data used with the model were records of individual detections at each downstream location. Detection histories also provided records of tagged study fish that were incidentally removed from the system due to transportation or other terminal sampling.

Data from PIT-tag detections of AT and PIT-tagged fish were retrieved from PTAGIS and checked for errors. Pre-release mortalities and fish that were determined to have lost tags before release were excluded from analyses. For yearling Chinook salmon, pre-release mortality was 0-2% (0-9 fish) per replicate for AT releases and 0% (9-25 fish) per replicate for PIT-tagged releases. For subyearling Chinook, pre-release mortality was 0-2% (0-5 fish) per replicate for AT releases, 0-7% (0-7 fish) per replicate for the AT pilot releases, and 0-1% (0-9 fish) for PIT-tagged releases. Both AT and PIT-tag loss prior to release was negligible for all groups.

Detection Probability Estimates—Acoustic- and PIT-tag detection sites are shown in Figure 1. For PIT-tag only fish, detection sites were Snake and Columbia River dams and the estuary trawl PIT-tag detection system. For AT fish, both acoustic and PIT detection data were used in detection probability estimates. Given the generally higher detection rates of AT transmitters, combining the PIT and AT data provided more precise estimates of survival than would have been possible using only PIT-tag detections of AT fish.

In addition, combining data from both tag technologies allowed us to compensate for bias in relative survival estimates that may have resulted from loss of PIT-tags in AT fish. In our analysis, the PIT-tag detection probabilities of AT fish were adjusted downward (and survival probabilities upward) for locations where an AT fish with no PIT detection was later detected downstream on an acoustic node. This adjustment for the AT group was necessary for all detection probability estimates except for yearling Chinook salmon at Lower Monumental Dam. A description of how the CJS model was used with both types of data is presented in Appendix C.

For example, detection probabilities at Ice Harbor, Lower Monumental, and McNary Dam were estimated using PIT tag detections downstream from these locations combined with AT detections from an acoustic array near Irrigon, Oregon. Detection probabilities at John Day Dam were estimated with PIT-tag detections downstream, combined with AT detections from an acoustic array at Bonneville Dam tailrace. Detection probability at Bonneville Dam was estimated using PIT-tag detections in the estuary trawl system combined with acoustic detections from multiple arrays below Bonneville Dam and in the estuary. Detail on acoustic receiver arrays and PIT-tag monitor locations is provided in Appendix A and D, respectively. All detection records are available online at www.nwfsc.noaa.gov/ publications/index.cfm.

Detection probability was compared between paired (by release replicate) tag treatment groups at each downstream dam. Comparisons were made using paired *t*-tests on the mean and standard error of estimated differences in detection probabilities between paired groups. The null hypothesis was that detection probability was equal between tag groups (i.e., the difference between detection probabilities equal zero). We calculated *t* and compared it to the *t*-variant with $\alpha = 0.05$ and with degrees of freedom equal to the number of pairs minus one.

Estimates of Relative Survival—Survival estimates for both PIT-tagged and AT fish were calculated based on PIT-tag detections at six Snake and Columbia River dams (Figure 1). Survival probabilities from release to each downstream dam were compared between paired tag treatment groups. These comparisons were made using paired *t*-tests on the mean and standard error of ratios of estimated survival between paired tag treatment groups (AT/PIT).

For these tests, we used log-transformed survival estimates of each ratio and assumed these ratios to be log-normally distributed (Snedecor and Cochran 1980). The mean and standard error were then back-transformed to provide estimates on the original scale (note for the mean this is the same as calculating the geometric mean of the original paired survival differences). The null hypothesis was that survival was equal between tag treatment groups (i.e., that the ratio between tag treatments equal one). We calculated *t* and compared it to the normal *t*-variant corresponding to $\alpha = 0.05$ with degrees of freedom equal to the number of pairs minus one.

Travel Time

Travel time was calculated for individual fish in PIT and AT groups from PIT-tag detection data that was retrieved from PTAGIS and checked for errors. Travel times were calculated from release in Lower Granite Dam tailrace to the following locations:

- Little Goose Dam (60 km),
- Lower Monumental Dam (106 km)
- Ice Harbor Dam (157 km)
- McNary Dam (225 km)
- John Day Dam (348 km)
- Bonneville Dam (460 km)

Travel time through a reach included delay in the forebay of a dam prior to passage and delay within the bypass system at a dam.

The true set of travel times for fish in a release group includes travel time of both detected and nondetected fish. However, travel time could not be determined for a fish that traversed a river section, but was not detected at one or both ends of the reach. Thus, travel-time statistics were estimated from travel time for detected fish only, with computations representing a sub-sample of the complete release group.

We estimated travel time for each release date separately due to temporal trend differences in travel times associated with environmental (e.g. river flow) and biological (e.g. smoltification) factors. A minimum of 10 fish from each release group had to be detected at a detection site for the group to be included in the travel time analysis. Subyearlings were grouped by week of release because relatively low numbers of acoustic-tagged subyearlings were detected from each individual release date at downstream detection sites.

Additionally, detections that occurred 55 d after the tag-activation date (the minimum life of the acoustic transmitters) were removed from the data. Median travel time to each detection site was calculated for each release group. The median was more useful as an indicator of typical travel time due to the longer right tail of individual distributions (i.e., presence of "stragglers"). For each release group, the 10th and 90th percentiles of travel time to each detection site were used to develop 90% CIs around the median. At each downstream detection site, medians for all releases by tag type were then averaged to obtain an overall mean travel time for each tag treatment. Overall mean travel times between release and each downstream detection site (and 95% CIs) were then used to test the null hypothesis, that acoustic- and PIT-tagged groups traveled at equal rates.

Avian Predation

NOAA Fisheries and the Columbia Bird Research group annually monitor selected avian nesting colonies within the basin for PIT tags deposited by predatory waterbirds. Physical recovery and electronic detection of PIT tags on piscivorous bird colonies are conducted during fall each year, after the birds have abandoned the colonies. Data collected during fall 2007 were provided by NOAA Fisheries (D. Ledgerwood, NOAA Fisheries personal communication) and Real Time Research, Inc. (A. Evans, Real Time Research, Inc., personal communication), and included predation information from Caspian tern *Sterna caspia*, double-crested cormorant *Phalacrocorax aurtius*, and gull *Larus* spp. colonies.

Differences in the percent of tags recovered (by location and colony) were compared between AT and PIT-tagged fish using the methodology described above for PIT-tag detection probability at dams. In an attempt to adjust for unequal survival downstream between the two treatment groups, we multiplied the individual cohort release numbers by survival from Lower Granite Dam to Lower Monumental Dam (for upper river bird colonies) and to Bonneville or John Day Dams (for estuarine bird colonies in spring and summer, respectively) before calculating the proportion of fish known to be consumed. Due to a combination of low survival to the lower river, as well as very low PIT-tag recoveries from releases of subyearling Chinook on or after 30 June, avian predation was compared only for subyearling Chinook groups released prior to this date. There were no recoveries on bird colonies of tags from AT pilot subyearling fish, so no assessments of avian predation were made for this group.

Results

Yearling Chinook Salmon

Detection Probability Estimates—Of the 3,818 AT fish and 46,714 PIT-tagged fish released into the tailrace of Lower Granite Dam, there were 3,508 and 45,347 first-time PIT-tag detections, respectively, at downstream dams on the Snake and Columbia Rivers (Appendix D). Detection probabilities varied among release groups and detection locations, ranging from a low of 0.05 to a high of 0.39 (Figure 9; Tables 5-6). The lowest PIT-tag detection probabilities were observed at Ice Harbor (AT 0.06; PIT 0.05) and Bonneville Dam (AT 0.10; PIT 0.13). The highest detection probabilities were observed at McNary (AT 0.35; PIT 0.38) and John Day Dam (AT 0.39; PIT 0.38; Figure 9). Mean detection probability at Little Goose was 0.20 for AT fish and 0.17 for PIT-tagged fish. At Lower Monumental Dam, mean detection probability was 0.17 for AT compared to 0.16 for PIT-tagged yearling Chinook.

Overall, mean PIT-tag detection probabilities between AT and PIT-tagged fish differed significantly ($\alpha = 0.05$) at three of the six detection sites (Tables 5 and 6). At Little Goose Dam, overall mean PIT-tag detection probability of AT fish was 0.03 greater than that of PIT-tagged fish ($P = 0.004$; Table 5). Conversely, detection probabilities of PIT-tagged fish were 0.03 greater than those of AT fish at both McNary ($P = 0.018$) and Bonneville Dam ($P = 0.010$; Table 6).

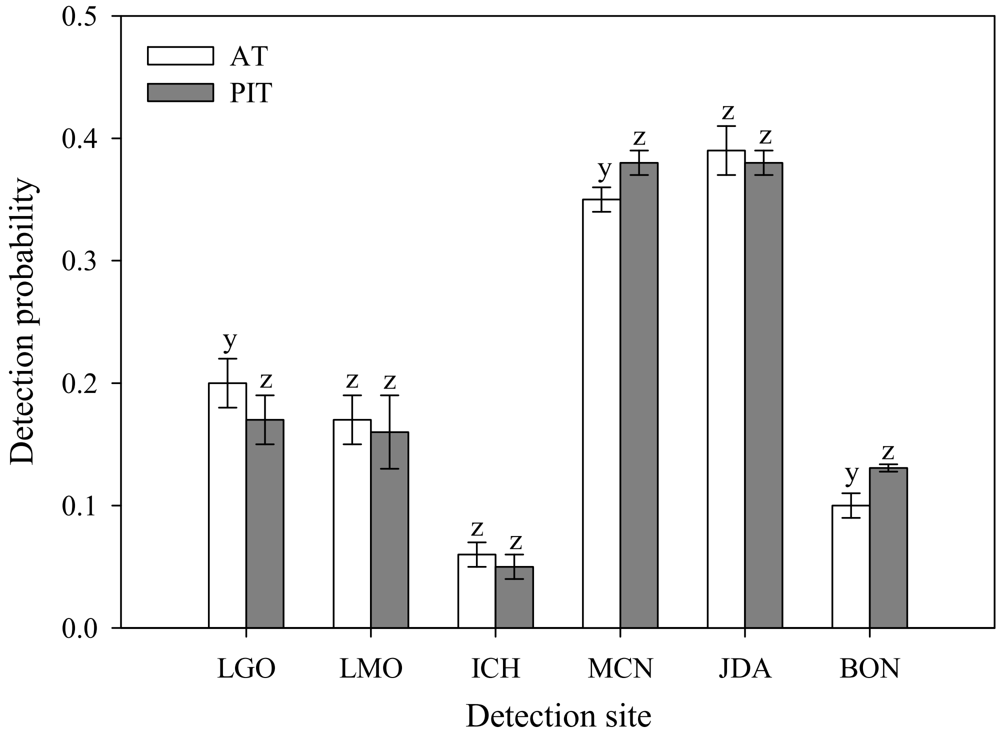


Figure 9. Mean PIT-tag detection probability of AT and PIT-tagged yearling Chinook salmon at each detection site on the Snake and Columbia Rivers in 2007. Abbreviation of dams: LGO, Little Goose; LMO, Lower Monumental; ICH, Ice Harbor; MCN, McNary; JDA, John Day; BON, Bonneville. Error bars denote standard errors. Dissimilar letters indicate a significant difference ($\alpha = 0.05$) between groups at each detection site.

Table 5. Mean PIT tag detection probability and *t*-test results at each detection site in the Snake River for AT and PIT river-run yearling Chinook salmon released into the Lower Granite Dam tailrace in 2007. Standard errors are in parentheses.

Detection point	Release date	Mean detection probability AT	Mean detection probability PIT	*t*	*P*
Little Goose Dam	25 April	0.15 (0.02)	0.10 (0.01)		
	26 April	0.16 (0.02)	0.12 (0.01)		
	28 April	0.19 (0.02)	0.18 (0.01)		
	1 May	0.23 (0.03)	0.19 (0.01)		
	3 May	0.14 (0.02)	0.11 (< 0.01)		
	5 May	0.09 (0.02)	0.10 (0.01)		
	9 May	0.24 (0.02)	0.20 (0.01)		
	10 May	0.31 (0.03)	0.31 (0.01)		
	12 May	0.29 (0.03)	0.24 (0.01)		
	15 May	0.24 (0.03)	0.16 (0.01)		
	Mean	**0.20 (0.02)**	**0.17 (0.02)**	**3.89**	**0.004**
Lower Monumental Dam	25 April	0.17 (0.02)	0.16 (0.01)		
	26 April	0.16 (0.02)	0.17 (0.01)		
	28 April	0.14 (0.02)	0.18 (0.01)		
	1 May	0.14 (0.02)	0.11 (0.01)		
	3 May	0.05 (0.01)	0.03 (< 0.01)		
	5 May	0.17 (0.02)	0.13 (0.01)		
	9 May	0.31 (0.03)	0.32 (0.01)		
	10 May	0.24 (0.03)	0.25 (0.01)		
	12 May	0.10 (0.02)	0.09 (0.01)		
	15 May	0.19 (0.02)	0.17 (0.01)		
	Mean	**0.17 (0.02)**	**0.16 (0.03)**	**0.56**	**0.590**
Ice Harbor Dam	25 April	0.05 (0.01)	0.07 (0.01)		
	26 April	0.09 (0.02)	0.07 (0.01)		
	28 April	0.07 (0.01)	0.05 (0.01)		
	1 May	0.07 (0.02)	0.04 (< 0.01)		
	3 May	0.06 (0.02)	0.03 (< 0.01)		
	5 May	0.12 (0.02)	0.09 (0.01)		
	9 May	0.05 (0.01)	0.05 (0.01)		
	10 May	0.05 (0.02)	0.05 (< 0.01)		
	12 May	0.05 (0.01)	0.06 (< 0.01)		
	15 May	0.03 (0.01)	0.02 (< 0.01)		
	Mean	**0.06 (0.01)**	**0.05 (0.01)**	**1.65**	**0.134**

Table 6. Mean PIT-tag detection probability and *t*-test results at each detection site in the Columbia River for AT and PIT-tagged river-run yearling Chinook salmon released into the Lower Granite Dam tailrace in 2007 . Standard errors are in parentheses.

		Mean detection probability			
Detection point	Release date	AT	PIT	*t*	*P*
McNary Dam	25 April	0.34 (0.03)	0.42 (0.01)		
	26 April	0.37 (0.03)	0.38 (0.01)		
	28 April	0.33 (0.03)	0.37 (0.01)		
	1 May	0.38 (0.03)	0.36 (0.01)		
	3 May	0.33 (0.03)	0.33 (0.01)		
	5 May	0.30 (0.03)	0.33 (0.01)		
	9 May	0.32 (0.03)	0.33 (0.01)		
	10 May	0.37 (0.03)	0.39 (0.01)		
	12 May	0.36 (0.03)	0.42 (0.01)		
	15 May	0.40 (0.03)	0.42 (0.01)		
	Mean	**0.35 (0.01)**	**0.38 (0.01)**	**2.88**	**0.018**
John Day Dam	25 April	0.38 (0.03)	0.45 (0.02)		
	26 April	0.46 (0.04)	0.42 (0.03)		
	28 April	0.47 (0.04)	0.42 (0.03)		
	1 May	0.45 (0.04)	0.37 (0.02)		
	3 May	0.39 (0.04)	0.33 (0.02)		
	5 May	0.34 (0.03)	0.33 (0.02)		
	9 May	0.41 (0.04)	0.35 (0.02)		
	10 May	0.31 (0.04)	0.41 (0.02)		
	12 May	0.33 (0.05)	0.36 (0.02)		
	15 May	0.36 (0.04)	0.39 (0.03)		
	Mean	**0.39 (0.02)**	**0.38 (0.01)**	**0.37**	**0.721**
Bonneville Dam	25 April	0.12 (0.02)	0.11 (0.03)		
	26 April	0.09 (0.02)	0.12 (0.04)		
	28 April	0.11 (0.02)	0.13 (0.04)		
	1 May	0.08 (0.02)	0.14 (0.03)		
	3 May	0.12 (0.03)	0.14 (0.02)		
	5 May	0.14 (0.02)	0.14 (0.03)		
	9 May	0.06 (0.02)	0.12 (0.04)		
	10 May	0.10 (0.03)	0.11 (0.03)		
	12 May	0.04 (0.02)	0.13 (0.04)		
	15 May	0.09 (0.02)	0.16 (0.04)		
	Mean	**0.10 (0.01)**	**0.13 (< 0.01)**	**3.27**	**0.010**

Estimates of Relative Survival—Relative survival is defined as the ratio of mean survival estimates for AT and PIT-tagged fish. From release to Little Goose Dam, relative survival was not different between tag treatment groups (AT/PIT = 1.00). Relative survival from release to Ice Harbor Dam was 0.92, and was not significantly different between tag treatment groups ($P = 0.285$; Table 7). However, from release to Lower Monumental Dam survival was significantly higher for AT fish at the 0.080 level (AT/PIT = 1.05). Within the Columbia River, higher mean survival was observed for PIT-tagged fish than AT fish at each of the three detection sites downstream from Lower Granite Dam. Relative survival from release to McNary, John Day, and Bonneville Dams was 0.92 ($P = 0.054$), 0.86 ($P = 0.010$), and 0.79 ($P = 0.001$) respectively.

All AT fish except those from the last release group had higher probabilities of survival from release to Lower Monumental Dam than PIT-tagged fish (Table 7; Figure 10). At Ice Harbor Dam, differences in survival between AT and PIT-tagged fish were inconsistent throughout the study period. For the first five release groups, survival of PIT-tagged fish was higher than that of AT fish from release to Ice Harbor Dam. This trend reversed for the last five release groups, when AT fish had a higher probability of survival compared to PIT-tagged fish.

Relative survival from release to McNary Dam varied somewhat throughout the field season (Table 8; Figure 11A). With the exception of releases on 10 and 15 May, estimated survival to McNary Dam was higher for PIT-tagged than AT fish. For fish released on 26 April and 1 and 3 May, estimated survival to McNary Dam was much greater for PIT than AT fish. Relative survival of yearling Chinook salmon to John Day Dam salmon followed a pattern similar to that observed at McNary Dam. For all paired tag-treatment releases with the exception of those on 10 and 15 May, survival estimates were higher for PIT-tagged than AT fish (Table 8, Figure 11B). At Bonneville Dam, the pattern continued, with higher survival estimates for PIT-tagged than AT yearling Chinook in 9 of 10 paired releases (Table 8; Figure 11C). Estimated survival was higher for AT than PIT-tagged fish only in the release group on 15 May.

Table 7. Mean survival probability and *t*-test results from release to downstream detection sites in the Snake River for AT and PIT river-run yearling Chinook salmon released into the Lower Granite Dam tailrace in 2007. The *t*-test was based on the geometric mean of the replicate survival ratio (AT/PIT) for each location. Standard errors are in parentheses.

		Mean survival probability of yearling Chinook salmon from Lower Granite Dam			
Detection site	Release date	Acoustic tagged	PIT tagged	*t*	*P*
Little Goose Dam	25 Apr	0.87 (0.05)	0.96 (0.03)		
	26 Apr	0.88 (0.06)	0.96 (0.03)		
	28 Apr	0.95 (0.06)	0.92 (0.03)		
	1 May	0.90 (0.06)	0.91 (0.03)		
	3 May	0.95 (0.09)	0.95 (0.03)		
	5 May	1.02 (0.09)	0.85 (0.03)		
	9 May	0.92 (0.04)	0.91 (0.02)		
	10 May	0.93 (0.04)	0.90 (0.02)		
	12 May	0.91 (0.05)	0.95 (0.02)		
	15 May	0.93 (0.05)	0.99 (0.03)		
	Mean	**0.93 (0.01)**	**0.93 (0.01)**	**0.14**	**0.893**
Lower Monumental Dam	25 Apr	0.88 (0.05)	0.85 (0.02)		
	26 Apr	0.87 (0.06)	0.82 (0.02)		
	28 Apr	0.97 (0.08)	0.88 (0.03)		
	1 May	0.84 (0.07)	0.84 (0.03)		
	3 May	1.15 (0.22)	0.94 (0.05)		
	5 May	0.90 (0.05)	0.88 (0.03)		
	9 May	0.87 (0.04)	0.84 (0.02)		
	10 May	0.92 (0.05)	0.91 (0.02)		
	12 May	1.01 (0.13)	0.93 (0.04)		
	15 May	0.82 (0.05)	0.89 (0.03)		
	Mean	**0.92 (0.03)**	**0.88 (0.01)**	**1.98**	**0.080**
Ice Harbor Dam	25 Apr	0.73 (0.02)	0.81 (0.03)		
	26 Apr	0.77 (0.07)	0.82 (0.04)		
	28 Apr	0.80 (0.07)	0.90 (0.06)		
	1 May	0.68 (0.06)	0.85 (0.06)		
	3 May	0.76 (0.10)	0.91 (0.05)		
	5 May	0.87 (0.06)	0.83 (0.03)		
	9 May	0.88 (0.10)	0.81 (0.06)		
	10 May	0.96 (0.14)	0.89 (0.06)		
	12 May	0.81 (0.12)	0.81 (0.04)		
	15 May	0.87 (0.15)	0.80 (0.07)		
	Mean	**0.81 (0.03)**	**0.84 (0.01)**	**1.14**	**0.285**

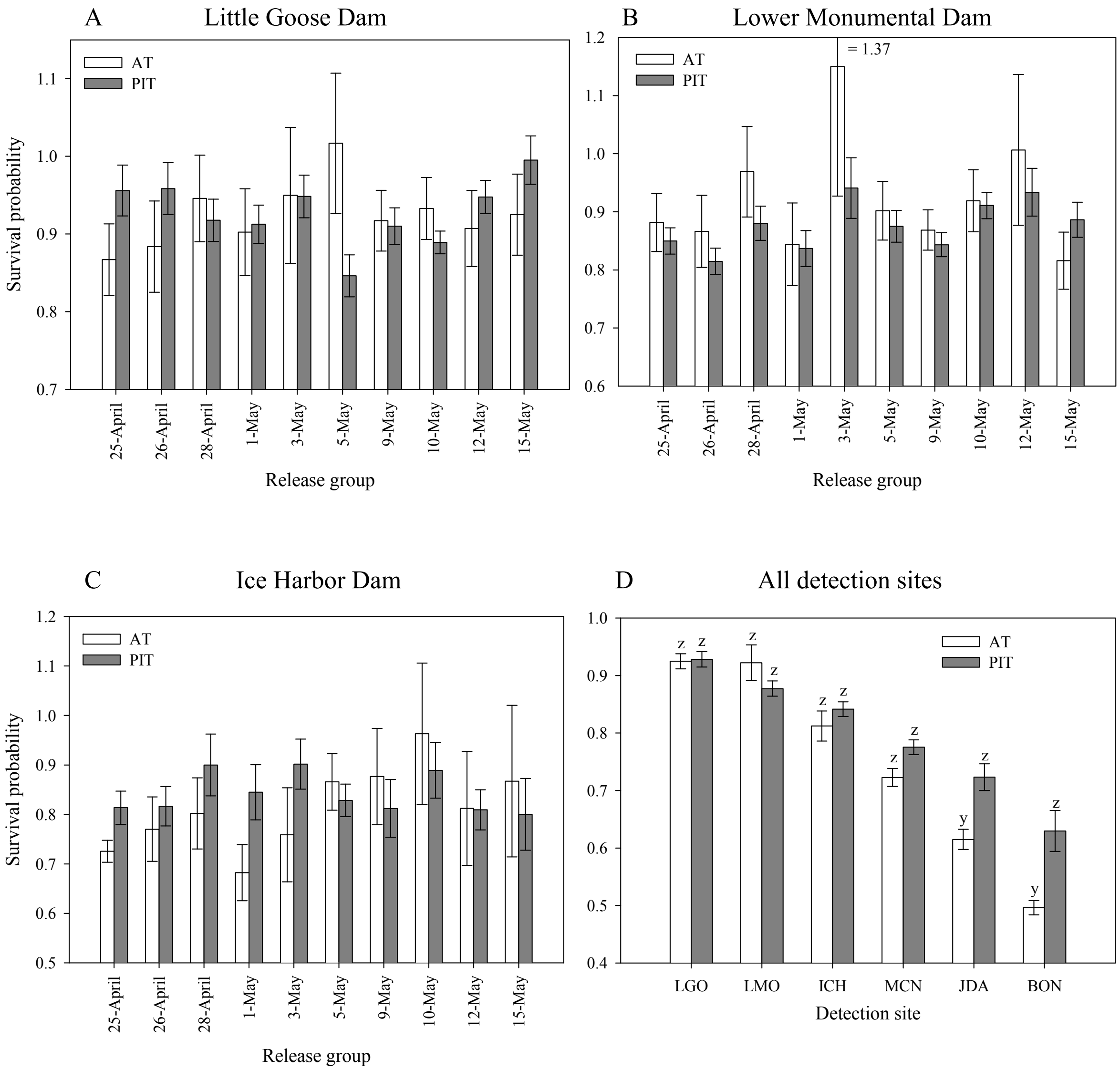


Figure 10. Mean survival probabilities by release date of AT and PIT-tagged yearling Chinook salmon from Lower Granite Dam tailrace to detection at A) Little Goose, B) Lower Monumental, C) Ice Harbor, and D) all detection sites (for the combined releases). Whisker bars denote standard errors. Dissimilar letters indicate a significant difference in estimated survival between tag treatments ($\alpha = 0.05$). Abbreviations: LGO, Little Goose; LMO Lower Monumental; ICH Ice Harbor, MCN McNary, JDA John Day, BON Bonneville.

Table 8. Mean survival probability and *t*-test results from release to each detection site on the Columbia River for AT and PIT tagged river-run yearling Chinook salmon released to the Lower Granite Dam tailrace in 2007. Standard errors are in parentheses. The *t*-test was based on the geometric mean of the replicate survival ratio (AT/PIT) for each location.

Reach evaluated	Release date	Mean survival probability AT	Mean survival probability PIT	*t*	*P*
Lower Granite to McNary tailrace	25 April	0.76 (0.03)	0.81 (0.02)		
	26 April	0.70 (0.03)	0.81 (0.02)		
	28 April	0.76 (0.03)	0.76 (0.02)		
	1 May	0.65 (0.03)	0.82 (0.02)		
	3 May	0.64 (0.03)	0.83 (0.02)		
	5 May	0.77 (0.03)	0.79 (0.02)		
	9 May	0.75 (0.03)	0.75 (0.03)		
	10 May	0.78 (0.03)	0.74 (0.02)		
	12 May	0.69 (0.03)	0.73 (0.02)		
	15 May	0.74 (0.03)	0.72 (0.02)		
	Mean	**0.72 (0.02)**	**0.78 (0.01)**	**2.21**	**0.054**
Lower Granite to John Day tailrace	25 April	0.68 (0.04)	0.70 (0.03)		
	26 April	0.62 (0.03)	0.74 (0.04)		
	28 April	0.63 (0.04)	0.71 (0.04)		
	1 May	0.51 (0.04)	0.81 (0.05)		
	3 May	0.54 (0.04)	0.78 (0.03)		
	5 May	0.68 (0.04)	0.80 (0.04)		
	9 May	0.60 (0.03)	0.72 (0.05)		
	10 May	0.67 (0.05)	0.64 (0.03)		
	12 May	0.59 (0.06)	0.76 (0.05)		
	15 May	0.62 (0.05)	0.58 (0.04)		
	Mean	**0.62 (0.02)**	**0.72 (0.02)**	**3.25**	**0.010**
Lower Granite to Bonneville tailrace	25 April	0.56 (0.03)	0.79 (0.20)		
	26 April	0.52 (0.04)	0.76 (0.24)		
	28 April	0.52 (0.04)	0.55 (0.15)		
	1 May	0.47 (0.07)	0.58 (0.14)		
	3 May	0.48 (0.04)	0.63 (0.10)		
	5 May	0.53 (0.03)	0.63 (0.12)		
	9 May	0.50 (0.03)	0.71 (0.21)		
	10 May	0.52 (0.05)	0.64 (0.15)		
	12 May	0.43 (0.03)	0.61 (0.17)		
	15 May	0.45 (0.06)	0.39 (0.09)		
	Mean	**0.50 (0.01)**	**0.63 (0.04)**	**4.87**	**0.001**

A McNary Dam

B John Day Dam

C Bonneville Dam

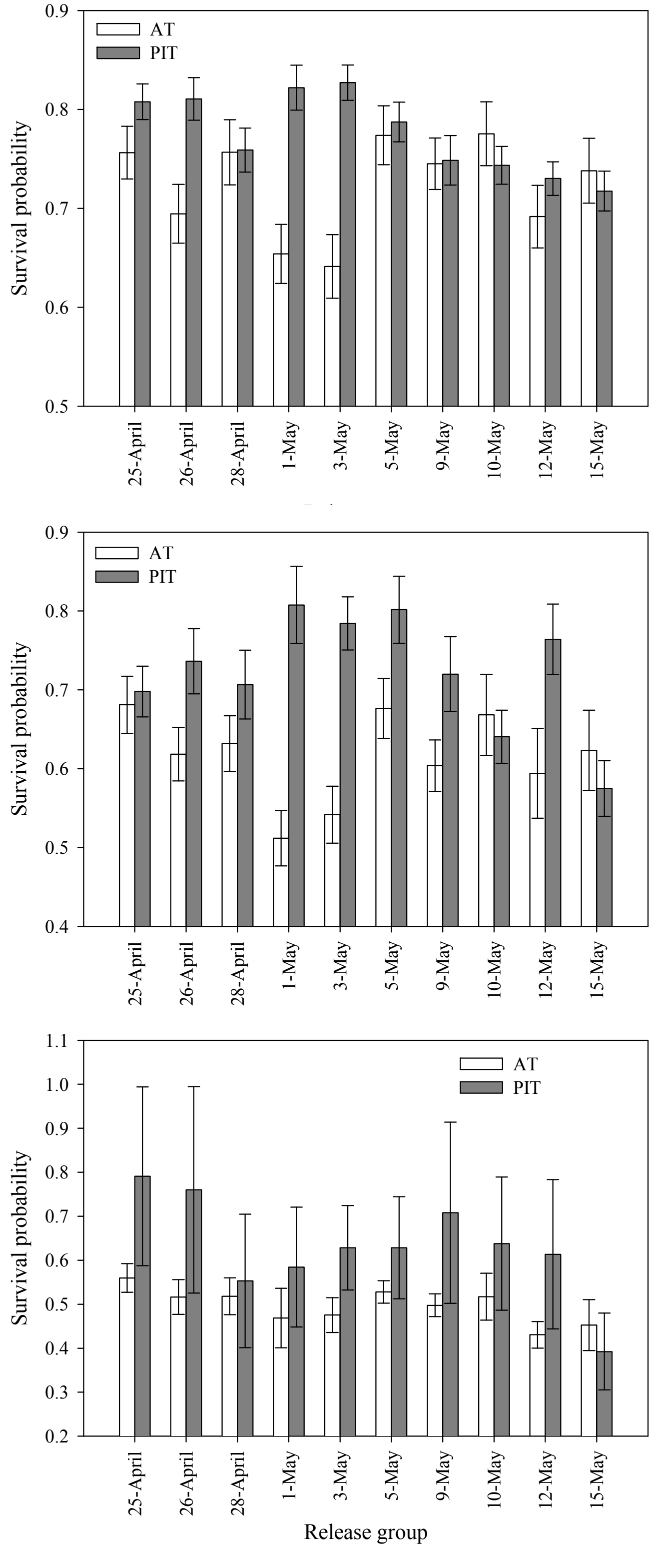


Figure 11. Mean survival probabilities of AT and PIT river-run yearling Chinook salmon from release at Lower Granite Dam to Columbia River detection sites at A) McNary, B) John Day, and C) Bonneville Dam in 2007. Whisker bars denote standard errors.

Travel Time—Median travel time to each downstream PIT-tag detection site was calculated for every release group with 10 or more detections of yearling Chinook salmon at that site. For every AT and every PIT-tag treatment release group, 10 or more fish were detected at each downstream site with one exception: only 9 AT fish from the 15 May release were detected at Ice Harbor Dam. Therefore, these data were not included in the travel time analyses. The greatest number of PIT-tag detections occurred at McNary Dam, where 948 AT and 13,472 PIT-tagged fish were detected throughout the season. At each downstream detection site, the overall mean, or the mean of all median travel times for each release group, was compared by tag treatment.

Overall mean travel time from Lower Granite Dam to all downstream detection sites was slightly longer for AT than PIT-tagged fish (Figure 12). However, the only significant difference in travel time between tag treatments was at John Day Dam, where overall mean travel time was 0.5 d longer for AT than for PIT-tagged fish ($P = 0.041$). At all other downstream detection sites, differences in overall mean travel time between treatments ranged from 0.0 to 0.3 d. Based on travel time data, it is likely that AT and PIT-tagged fish experienced similar environmental conditions and encountered similar hydropower operational modes at most detection locations, including locations where detection probabilities differed significantly between groups.

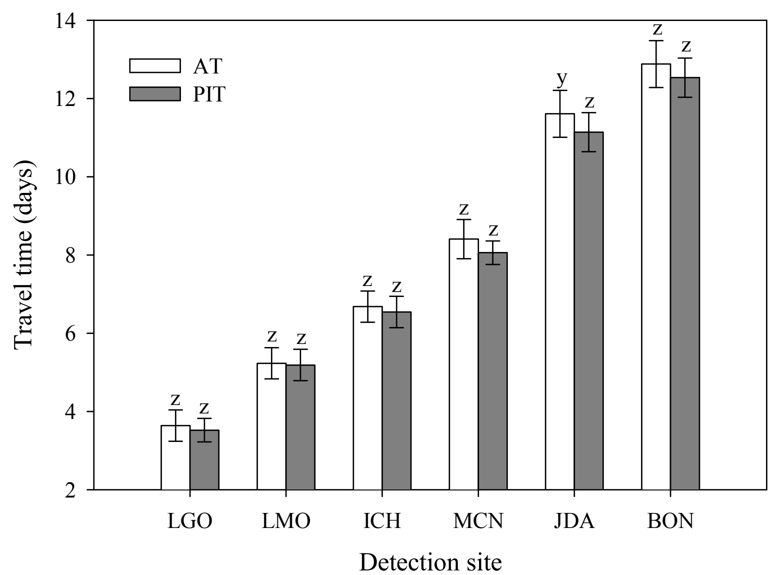


Figure 12. Mean travel time for combined release groups of AT and PIT-tagged yearling Chinook salmon from release at Lower Granite Dam to detection at downstream dams on the Snake and Columbia River, 2007. Whisker bars denote standard errors. Abbreviations: LGO, Little Goose Dam; LMO, Lower Monumental Dam; ICH, Ice Harbor Dam; MCN, McNary Dam; JDA, John Day Dam; BON, Bonneville Dam.

Median travel times of AT and PIT release groups to Little Goose and Lower Monumental Dams followed the same general trend seen in the overall means, and travel time appeared to be correlated with discharge (*r* = 0.88; Appendix Table F3). The first releases of test fish from both tag treatments (24 April) had the greatest median travel time to both dams (Figures 13A and B). Median travel time then fluctuated, decreasing for releases between 24 April and 3 May, increasing for releases between 1 and 8 May, decreasing again for releases between 5 and 15 May, and finally increasing for the last release on 15 May. In general, fish released on 1 May and during 8-15 May had the lowest median travel time to downstream dams.

At Ice Harbor Dam, the trend in median travel time deviated only slightly from that seen at Little Goose and Lower Monumental Dams and in the overall means. Similar to trends at these sites, the first release group arriving at Ice Harbor Dam had the highest median travel time, while releases between 24 April and 3 May were faster (Figure 13). Median travel time to Ice Harbor then increased for releases on 3 May and decreased for releases on 5 and 8 May. Travel times were generally shorter for releases on 28 April and 1 May and for the later releases during 8–12 May.

Median travel time to each dam on the Columbia River followed a trend similar to that observed for Snake River dams. The first two release groups (24 and 26 April) experienced the longest travel times to McNary, John Day, and Bonneville Dams, followed by a decline in travel time for groups released on 28 April and 1 May (Figure 14A and 13C). Median travel time remained relatively low and constant for each group of fish released from 1 to 15 May, with the exception of the 5 May release, which had slightly longer travel times.

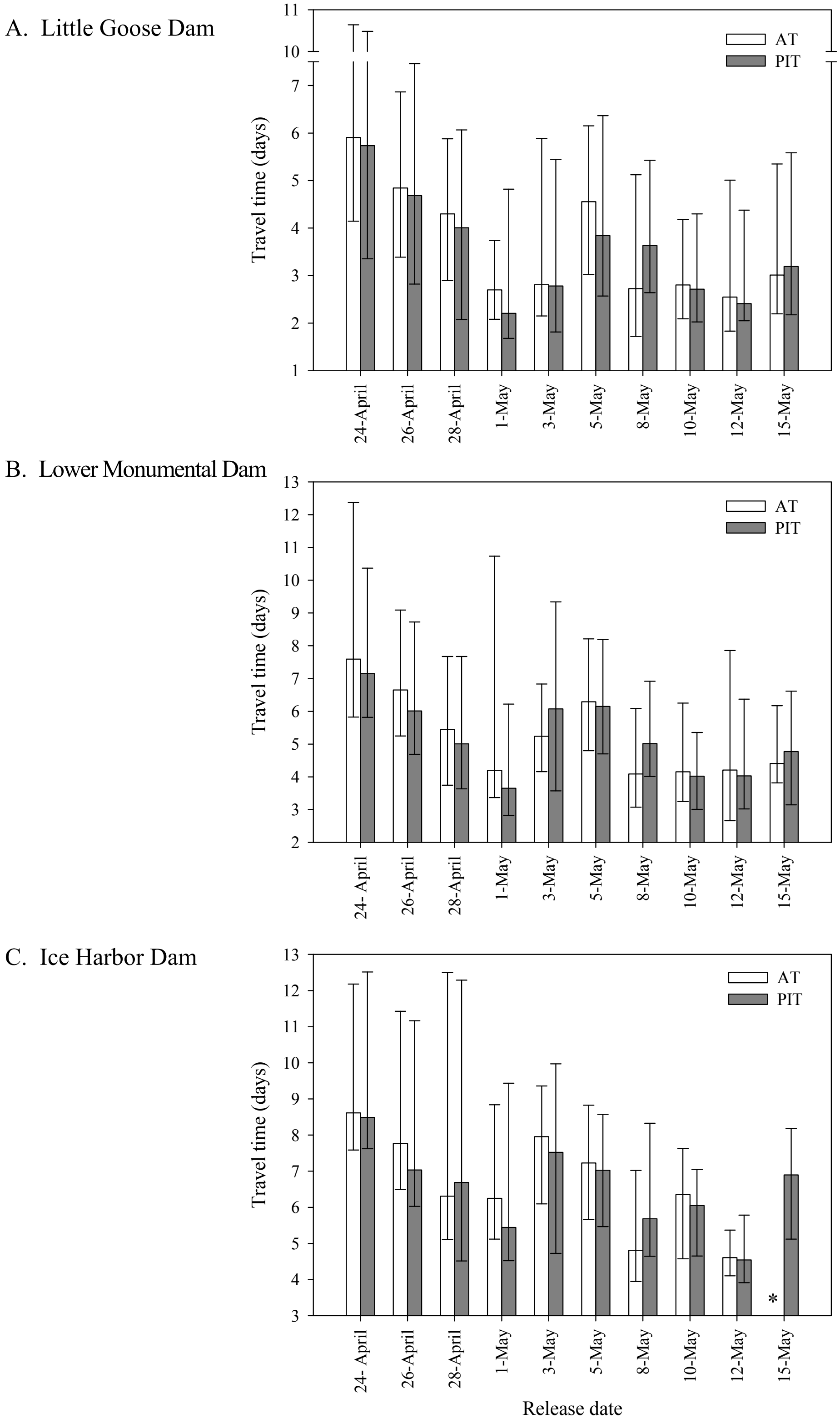
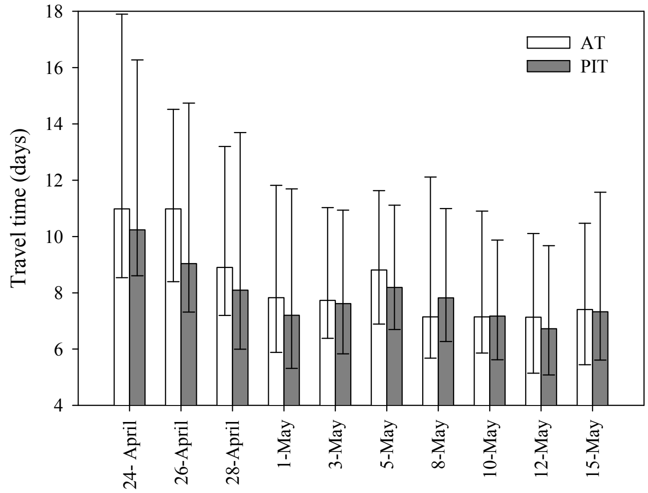
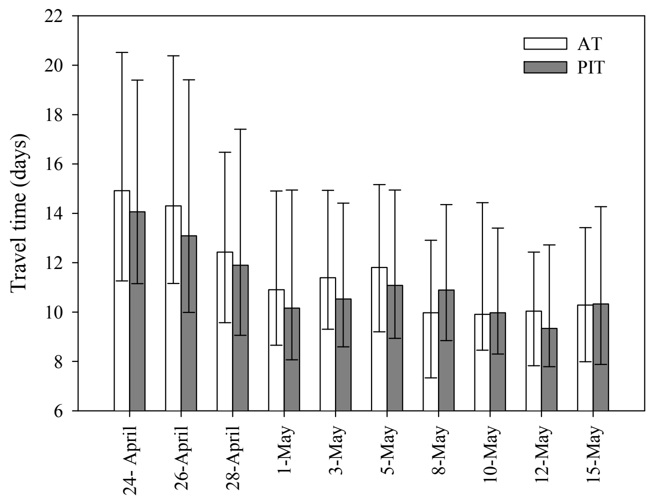


Figure 13. Median travel time by paired release to A) Little Goose, B) Lower Monumental, and C) Ice Harbor Dam on the Snake River for AT and PIT groups of yearling Chinook salmon released at Lower Granite Dam, 2007. Whisker bars denote 10th and 90th travel time percentiles from each release.

A. McNary Dam



B. John Day Dam



C. Bonneville Dam

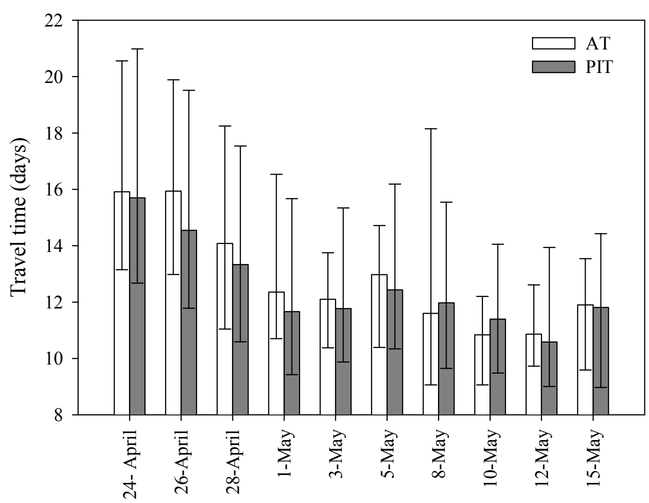


Figure 14. Median travel time by paired release to A) McNary, B) John Day, and C) Bonneville Dam on the Columbia River for AT and PIT yearling Chinook salmon release groups released at Lower Granite Dam in 2007. Whisker bars denote 10th and 90th travel time percentiles from each release.

Avian Predation—Recoveries of PIT-tags from study fish were combined for all upriver bird colonies sampled. From the combined total recoveries from upriver colonies, predation rates averaged 0.9% (range 0.0-1.8%) for AT releases and 1.0% (range = 0.5-1.6%) for PIT releases (Table 9). Estuary colonies sampled included only the tern and cormorant colonies on East Sand Island. Total PIT-tag recoveries from all colonies on East Sand Island averaged 3.3% (range 0.8-5.5%) for AT releases and 2.7% (range 2.0-3.4%) for PIT-tagged releases.

Differences in the proportion of PIT tags recovered on avian colonies were not significant between AT and PIT-tagged fish, either from the upriver ($P = 0.500$) or estuarine bird colonies ($P = 0.243$). Percentages of PIT tags recovered by individual colony and colony location were also similar between the two treatments (Table 10). These analyses were based on actual PIT detections and were not adjusted for detection efficiency rates. Since detection efficiency rates are not 100%, the estimates shown in Tables 9 and 10 represent minimum estimates of predation.

Table 9. Percentages of yearling Chinook PIT tags recovered from upriver and estuarine bird colonies in the Columbia River by tag treatment and release date. The actual number of tags recovered by colony is listed in parentheses.

Release date	Upriver bird colonies (%)	SE	Estuarine bird colonies (%)	SE	Overall from release (%)
			Acoustic-tagged yearling Chinook		
25 Apr	0.0 (0)	NA	3.5 (8)	1.2	2.0 (8)
26 Apr	0.9 (3)	0.5	3.4 (7)	1.3	2.5 (10)
28 Apr	1.8 (7)	0.7	2.4 (5)	1.1	3.0 (12)
1 May	0.9 (3)	0.5	3.7 (7)	1.5	3.5 (14)
3 May	0.0 (0)	NA	2.1 (4)	1.0	1.7 (7)
5 May	1.9 (7)	0.7	3.2 (7)	1.2	3.4 (14)
9 May	1.4 (5)	0.6	5.5 (11)	1.6	4.0 (16)
10 May	0.8 (2)	0.6	5.0 (7)	1.9	3.3 (9)
12 May	0.0 (0)	NA	0.8 (1)	0.8	0.7 (2)
15 May	0.7 (2)	0.5	3.0 (5)	1.4	1.9 (7)
Overall	0.9 (29)	0.2	3.3 (62)	0.3	2.6 (99)
			PIT-tagged yearling Chinook		
25 Apr	0.5 (18)	0.1	2.2 (79)	0.6	2.2 (97)
26 Apr	0.8 (26)	0.2	2.0 (58)	0.7	2.2 (84)
28 Apr	0.9 (25)	0.2	3.4 (63)	1.0	2.6 (88)
1 May	1.1 (34	0.2	3.2 (71)	0.8	2.8 (105)
3 May	0.9 (68)	0.1	2.3 (117)	0.4	2.3 (185)
5 May	0.9 (43)	0.1	2.9 (102)	0.6	2.6 (145)
9 May	1.4 (43)	0.2	2.5 (63)	0.8	3.0 (106)
10 May	0.9 (40)	0.1	3.4 (104)	0.9	3.0 (144)
12 May	1.0 (43)	0.2	2.7 (79)	0.8	2.5 (122)
15 May	1.6 (63)	0.2	2.4 (44)	0.7	2.3 (107)
Overall	1.0 (403)	0.0	2.7 (780)	0.1	2.5 (1183)
Mean difference (AT-PIT)	-0.2		0.5		
SE	0.2		0.4		
T	-0.70		1.25		
P	0.500		0.243		

Table 10. Percentages of PIT tags from AT and PIT-tagged yearling Chinook salmon that were subsequently recovered on avian predator colonies in 2007 by colony location, tag treatment, and release date. Numbers of tags recovered are shown in parentheses.

Release	Badger Island	Crescent Island		Foundation Isl	Miller Rocks	Miller Sands	Rock Island	East Sand Island	
date	Pelican	Gull	Tern	Cormorant	Gull	Cormorant	Tern	Cormorant	Tern
	Percent (%) and number (n) from acoustic-tagged river-run yearling Chinook salmon								
25 Apr	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.4 (1)	3.1 (7)
26 Apr	0.0 (0)	0.3 (1)	0.3 (1)	0.3 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	3.4 (7)
28 Apr	0.0 (0)	0.0 (0)	0.5 (2)	0.8 (3)	0.0 (1)	0.0 (0)	0.3 (1)	0.0 (0)	2.4 (5)
1 May	0.0 (0)	0.0 (0)	0.6 (2)	0.6 (2)	0.0 (1)	0.0 (0)	0.3 (1)	0.0 (0)	4.2 (8)
3 May	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (1)	0.0 (0)	0.0 (0)	1.0 (2)	2.1 (4)
5 May	0.0 (0)	0.0 (0)	0.3 (1)	1.6 (6)	0.0 (0)	0.0 (0)	0.0 (0)	0.9 (2)	2.3 (5)
9 May	0.0 (0)	0.6 (2)	0.0 (0)	0.9 (3)	0.0 (0)	0.0 (0)	0.0 (0)	2.0 (4)	3.5 (7)
10 May	0.0 (0)	0.0 (0)	0.0 (0)	0.4 (1)	0.0 (1)	0.0 (0)	0.0 (0)	1.4 (2)	3.5 (5)
12 May	0.0 (0)	0.0 (0)	0.0 (0)	0.3 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.8 (1)
15 May	0.0 (0)	0.0 (0)	0.0 (0)	0.7 (2)	0.0 (0)	0.0 (0)	0.0 (0)	0.6 (1)	2.4 (4)
Overall	0.0 (0)	0.1 (3)	0.2 (6)	0.6 (19)	0.1(4)	0.0 (0)	0.1 (2)	0.6 (12)	2.8 (53)
	Percent (%) and number (n) of tags from PIT-tagged river-run yearling Chinook salmon								
25 Apr	0.0 (0)	0.0 (0)	0.1 (3)	0.2 (6)	0.1 (4)	0.1 (3)	0.1 (2)	0.3 (11)	1.9 (68)
26 Apr	0.0 (0)	0.2 (5)	0.0 (1)	0.4 (11)	0.2 (5)	0.0 (1)	0.1 (3)	0.2 (5)	1.9 (53)
28 Apr	0.0 (0)	0.1 (3)	0.2 (6)	0.3 (10)	0.1 (3)	0.0 (1)	0.1 (2)	0.3 (6)	3.1 (57)
1 May	0.0 (1)	0.1 (3)	0.1 (2)	0.6 (18)	0.2 (5)	0.0 (1)	0.1 (4)	0.6 (14)	2.6 (57)
3 May	0.0 (1)	0.1 (9)	0.1 (10)	0.4 (30)	0.2 (13)	0.0 (3)	0.0 (2)	0.3 (17)	2.0 (100)
5 May	0.0 (1)	0.1 (3)	0.0 (2)	0.6 (29)	0.1 (6)	0.0 (0)	0.0 (2)	0.9 (31)	2.0 (71)
9 May	0.1 (2)	0.1 (4)	0.1 (4)	1.1 (32)	0.0 (1)	0.0 (0)	0.0 (0)	0.6 (15)	1.9 (48)
10 May	0.0 (0)	0.0 (3)	0.2 (7)	0.5 (21)	0.1 (5)	0.1 (2)	0.1 (2)	1.5 (46)	1.9 (58)
12 May	0.1 (3)	0.0 (4)	0.1 (5)	0.4 (19)	0.1 (8)	0.0 (2)	0.0 (2)	0.9 (26)	1.8 (53)
15 May	0.0 (0)	0.1 (4)	0.2 (6)	1.1 (43)	0.1(8)	0.0 (0)	0.1 (2)	0.3 (6)	2.1 (38)
Overall	0.0 (8)	0.1 (38)	0.1 (46)	0.5 (219)	0.1 (58)	0.0 (13)	0.1 (21)	0.6 (177)	2.1 (603)

Subyearling Chinook Salmon

Detection Probability Estimates—From the 7,736 AT subyearling Chinook salmon released to the tailrace of Lower Granite Dam, a total of 2,241 fish had first-time PIT-tag detections at downstream dams on the Snake and Columbia Rivers (Appendix A). For fish tagged with only a PIT tag, there were 11,570 first-time detections at downstream dams from 26,338 total fish released (Appendix D). Files containing records of all PIT and AT detections are available as electronic appendices on the Northwest Fisheries Science Center web site (www.nwfsc.noaa.gov/publications/scientificpubs.cfm).

For PIT-tagged fish, detection probabilities varied among release groups and detection locations (Figure 15; Tables 11-12). Mean detection probabilities were relatively high at Little Goose Dam, with detection rates of 0.33 for AT fish and 0.22 for PIT-tagged fish. Detection rates were similarly high at McNary Dam (0.24 and 0.21 for the AT and PIT-tagged fish respectively; Table 12). However, there were too few detections at all remaining locations for both treatment groups to calculate reliable estimates of detection or survival. For AT pilot fish, detection rates were insufficient at all downstream locations to estimate detection probability. Mean detection probability was significantly higher for AT than for PIT-tagged subyearling Chinook at Little Goose Dam (AT- PIT = 0.11, $P = 0.001$) but was similar between tag treatments at McNary Dam (AT- PIT = 0.03, $P = 0.505$) (Figure 15; Tables 11-12).

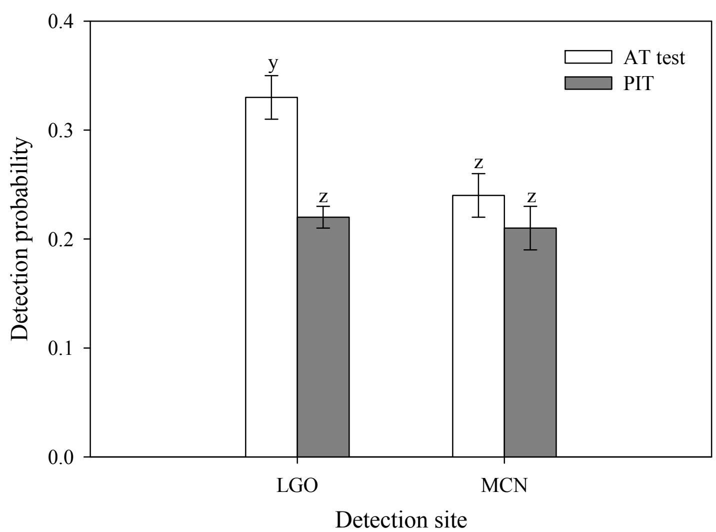


Figure 15. Mean PIT tag detection probability of AT and PIT-tagged subyearling Chinook salmon at Little Goose (LGO) and McNary (MCN) Dams in 2007. Error bars denote standard errors. Dissimilar letters indicate a significant difference between groups at a detection site (α = 0.05).

Table 11. Mean PIT-tag detection probability and *t*-test results at Little Goose Dam for AT and PIT subyearling Chinook salmon released to Lower Granite Dam tailrace in 2007. Standard errors are in parentheses. Asterisk denotes release group where detections were too low after release to calculate an estimate.

	Mean detection probability at Little Goose Dam for subyearling Chinook salmon	
Release date	Acoustic-tagged fish	PIT-tagged fish
5 June	0.26 (0.04)	0.16 (0.02)
6 June	0.32 (0.05)	0.27 (0.02)
7 June	0.34 (0.05)	0.27 (0.02)
8 June	0.30 (0.07)	0.26 (0.02)
9 June	0.34 (0.06)	0.30 (0.03)
12 June	0.47 (0.07)	0.21 (0.03)
13 June	0.49 (0.08)	0.27 (0.03)
14 June	0.37 (0.07)	0.23 (0.03)
15 June	0.30 (0.06)	0.26 (0.03)
16 June	0.33 (0.08)	0.23 (0.03)
19 June	0.31 (0.05)	0.17 (0.02)
20 June	0.23 (0.07)	0.17 (0.03)
21 June	0.17 (0.06)	0.15 (0.03)
22 June	0.24 (0.06)	0.13 (0.03)
23 June	0.12 (0.05)	0.13 (0.03)
26 June	0.44 (0.07)	0.20 (0.02)
27 June	0.21 (0.07)	0.21 (0.03)
28 June	0.28 (0.11)	0.22 (0.03)
29 June	0.41 (0.09)	0.23 (0.06)
30 June	0.44 (0.10)	0.22 (0.04)
3 July	0.42 (0.09)	0.27 (0.04)
4 July	0.29 (0.10)	0.25 (0.05)
5 July	0.28 (0.14)	0.37 (0.06)
6 July	0.40 (0.22)	0.24 (0.03)
12 July	0.33 (0.12)	0.21 (0.08)
13 July	0.50 (0.25)	0.10 (0.09)
14 July	*	0.32 (0.09)
Mean	0.33 (0.02)	0.22 (0.01)
t	3.73	
P	0.001	

Table 12. Mean PIT tag detection probability and *t*-test results at McNary Dam (MCN) for AT and PIT-tagged subyearling Chinook salmon released to Lower Granite Dam tailrace in 2007. Standard errors are in parentheses. Asterisk denotes release group where detections were too low after release to calculate an estimate.

Release date	Mean detection probability at McNary Dam for subyearling Chinook salmon	
	Acoustic-tagged fish	PIT-tagged fish
5 June	0.46 (0.05)	0.27 (0.03)
6 June	0.35 (0.05)	0.36 (0.03)
7 June	0.28 (0.05)	0.28 (0.03)
8 June	0.26 (0.06)	0.28 (0.03)
9 June	0.26 (0.05)	0.26 (0.03)
12 June	0.22 (0.06)	0.18 (0.04)
13 June	0.22 (0.07)	0.17 (0.03)
14 June	0.18 (0.06)	0.24 (0.04)
15 June	0.22 (0.06)	0.14 (0.03)
16 June	0.29 (0.08)	0.16 (0.03)
19 June	0.29 (0.06)	0.21 (0.04)
20 June	0.28 (0.08)	0.23 (0.05)
21 June	0.16 (0.06)	0.18 (0.04)
22 June	0.42 (0.07)	0.15 (0.04)
23 June	0.29 (0.06)	0.12 (0.03)
26 June	0.15 (0.05)	0.28 (0.04)
27 June	0.28 (0.08)	0.20 (0.04)
28 June	0.38 (0.12)	0.24 (0.05)
29 June	0.07 (0.05)	0.13 (0.07)
30 June	0.13 (0.07)	0.24 (0.06)
3 July	0.14 (0.06)	0.16 (0.04)
4 July	0.16 (0.08)	0.22 (0.06)
5 July	0.20 (0.13)	0.21 (0.07)
6 July	0.20 (0.18)	0.16 (0.04)
12 July	0.07 (0.07)	0.05 (0.05)
13 July	0.25 (0.22)	0.50 (0.20)
14 July	*	0.18 (0.09)
Mean	0.24 (0.02)	0.21 (0.02)
t	0.68	
P	0.505	

Estimates of Relative Survival—Detections of subyearling Chinook salmon were sufficient for estimates of survival only at Little Goose and McNary Dam. For AT pilot fish, detection rates were insufficient for survival estimates at all downstream locations. Survival was significantly higher for PIT-tagged than AT subyearlings to both Little Goose (AT/PIT = 0.80, P = 0.003) and McNary Dam (AT/PIT = 0.41, P = 0.001; Tables 13-14; Figure 16).

Relative survival varied much less from the first release date (5 June) until the end of June than it did towards the end of the season in mid-July. In the latter part of the season, a general trend of decreasing survival estimates for AT fish was apparent. At Little Goose Dam, this trend began with the 5 July release group and continued through the study period (Table 13; Figure 17). At McNary Dam, a trend of decreasing survival was observed for both AT and PIT-tagged subyearling fish, beginning with the release of 30 June and continuing through the remainder of the study period (Table 14; Figure 18).

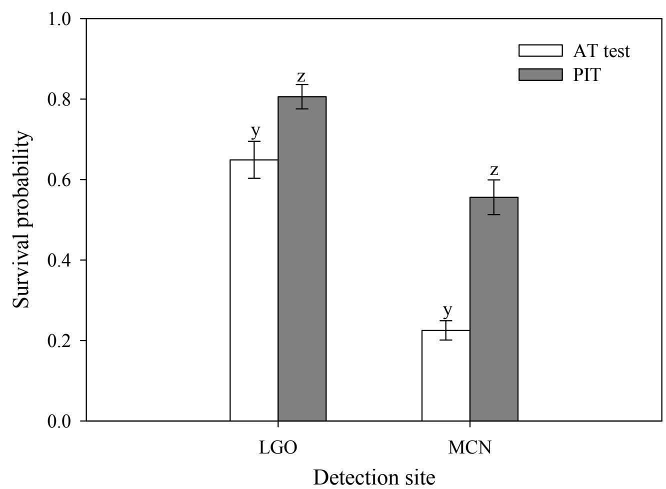


Figure 16. Survival probability of AT and PIT-tagged subyearling Chinook salmon between release in the tailrace of Lower Granite Dam to Little Goose (LGO) and McNary (MCN) Dams in 2007. Error bars denote standard errors. Dissimilar letters above pairs of bars indicate significant difference (α = 0.05) between groups at each detection site.

Table 13. Mean survival probability and *t*-test results for AT and PIT-tagged subyearling Chinook from release at Lower Granite Dam to Little Goose Dam in 2007. Standard errors are in parentheses. Asterisk denotes release group where detections were too low after release to calculate an estimate. The *t*-test was based on the geometric mean of the replicate survival ratio (AT/PIT) for each location.

	Mean survival probability (*S*) at Little Goose Dam for subyearling Chinook salmon	
Release date	AT fish	PIT-tagged fish
5 June	0.79 (0.09)	0.98 (0.09)
6 June	0.76 (0.08)	0.78 (0.05)
7 June	0.91 (0.10)	0.82 (0.05)
8 June	0.86 (0.17)	0.85 (0.07)
9 June	0.76 (0.11)	0.77 (0.06)
12 June	0.75 (0.11)	0.95 (0.11)
13 June	0.55 (0.08)	0.90 (0.08)
14 June	0.68 (0.12)	0.96 (0.11)
15 June	0.91 (0.18)	0.80 (0.09)
16 June	0.73 (0.16)	0.82 (0.08)
19 June	0.59 (0.09)	1.02 (0.13)
20 June	0.64 (0.18)	0.76 (0.12)
21 June	0.82 (0.26)	0.82 (0.14)
22 June	0.67 (0.14)	0.78 (0.15)
23 June	1.24 (0.44)	0.75 (0.13)
26 June	0.40 (0.05)	0.79 (0.09)
27 June	0.74 (0.22)	0.69 (0.08)
28 June	0.46 (0.16)	0.73 (0.09)
29 June	0.44 (0.08)	0.62 (0.14)
30 June	0.42 (0.09)	0.79 (0.13)
3 July	0.49 (0.10)	0.68 (0.09)
4 July	0.80 (0.26)	1.04 (0.18)
5 July	0.64 (0.30)	0.51 (0.08)
6 July	0.51 (0.27)	0.91 (0.12)
12 July	0.24 (0.08)	0.77 (0.27)
13 July	0.08 (0.04)	1.11 (1.04)
14 July	*	0.40 (0.10)
Mean	0.65 (0.05)	0.81 (0.03)
$t = 3.30$		
$P = 0.003$		

Table 14. Mean survival probability and *t*-test results for AT and PIT-tagged subyearling Chinook salmon from release at Lower Granite Dam to McNary Dam in 2007. Standard errors are in parentheses. Asterisk denotes release group where detections were too low after release to calculate an estimate. The *t*-test was based on the geometric mean of the replicate survival ratio (AT/PIT) for each location.

	Mean survival probability (*S*) at McNary Dam for subyearling Chinook salmon	
Release date	Acoustic-tagged fish	PIT-tagged fish
5 June	0.47 (0.04)	0.86 (0.09)
6 June	0.40 (0.04)	0.75 (0.06)
7 June	0.45 (0.05)	0.81 (0.09)
8 June	0.23 (0.04)	0.65 (0.07)
9 June	0.36 (0.05)	0.59 (0.07)
12 June	0.24 (0.05)	0.68 (0.12)
13 June	0.22 (0.05)	0.71 (0.11)
14 June	0.26 (0.07)	0.51 (0.07)
15 June	0.25 (0.05)	0.75 (0.16)
16 June	0.22 (0.05)	0.73 (0.13)
19 June	0.31 (0.04)	0.58 (0.09)
20 June	0.19 (0.04)	0.45 (0.08)
21 June	0.23 (0.06)	0.59 (0.12)
22 June	0.21 (0.03)	0.75 (0.20)
23 June	0.22 (0.04)	0.84 (0.20)
26 June	0.33 (0.09)	0.47 (0.06)
27 June	0.21 (0.05)	0.60 (0.11)
28 June	0.08 (0.02)	0.49 (0.09)
29 June	0.39 (0.23)	0.91 (0.47)
30 June	0.19 (0.08)	0.47 (0.11)
3 July	0.16 (0.05)	0.43 (0.11)
4 July	0.11 (0.04)	0.33 (0.07)
5 July	0.06 (0.03)	0.26 (0.08)
6 July	0.04 (0.02)	0.42 (0.10)
12 July	0.05 (0.04)	0.27 (0.25)
13 July	0.01 (0.01)	0.03 (0.01)
14 July	*	0.10 (0.05)
Mean	0.23 (0.02)	0.56 (0.04)
$t = 21.05$		
$P \leq 0.001$		

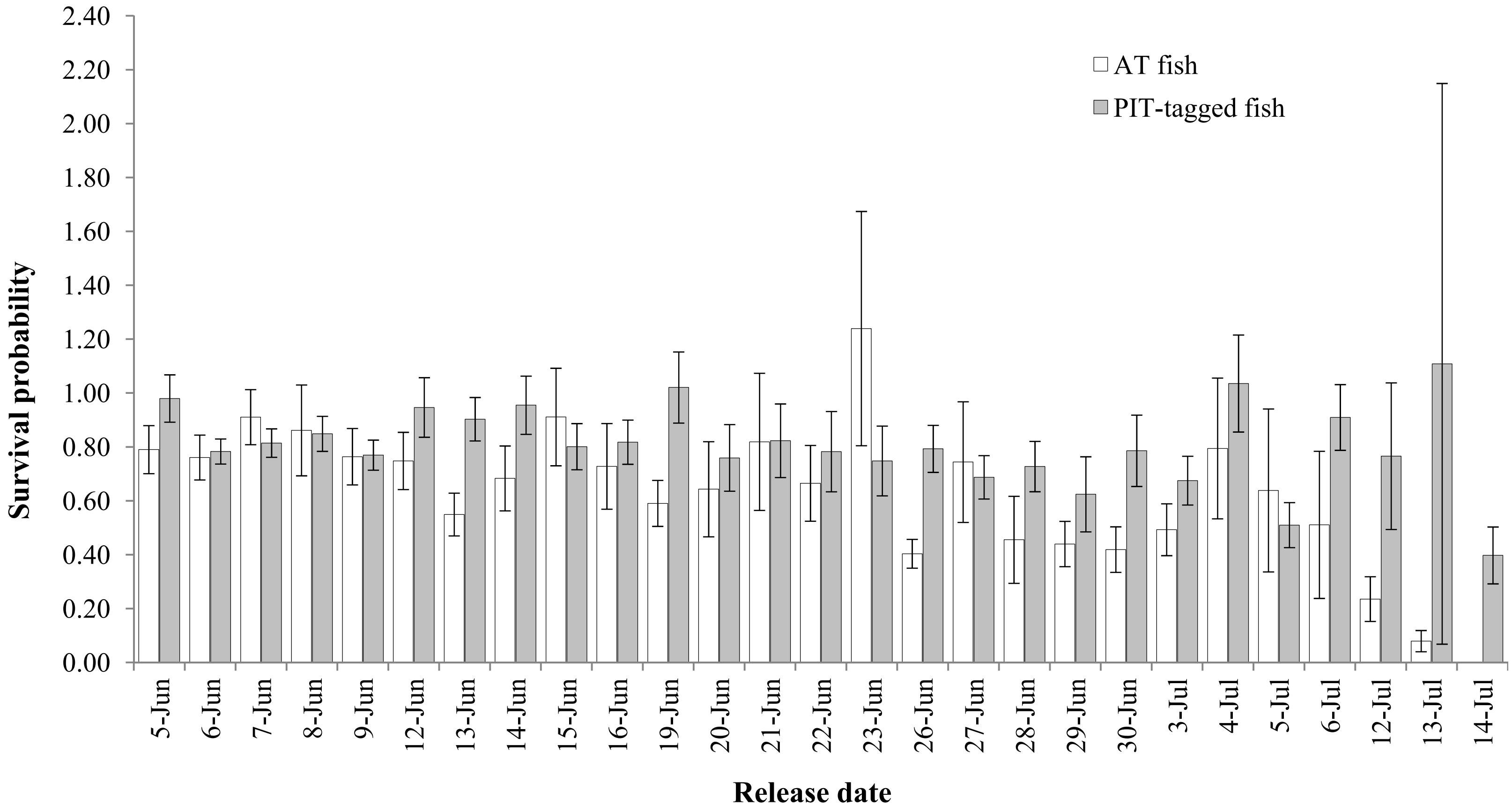


Figure 17. Survival probability of AT and PIT-tagged subyearling Chinook salmon from release at Lower Granite Dam to Little Goose Dam by release group in 2007. Error bars denote standard errors. For fish released on 14 July, the number of AT fish detected after release was too low to calculate an estimate.

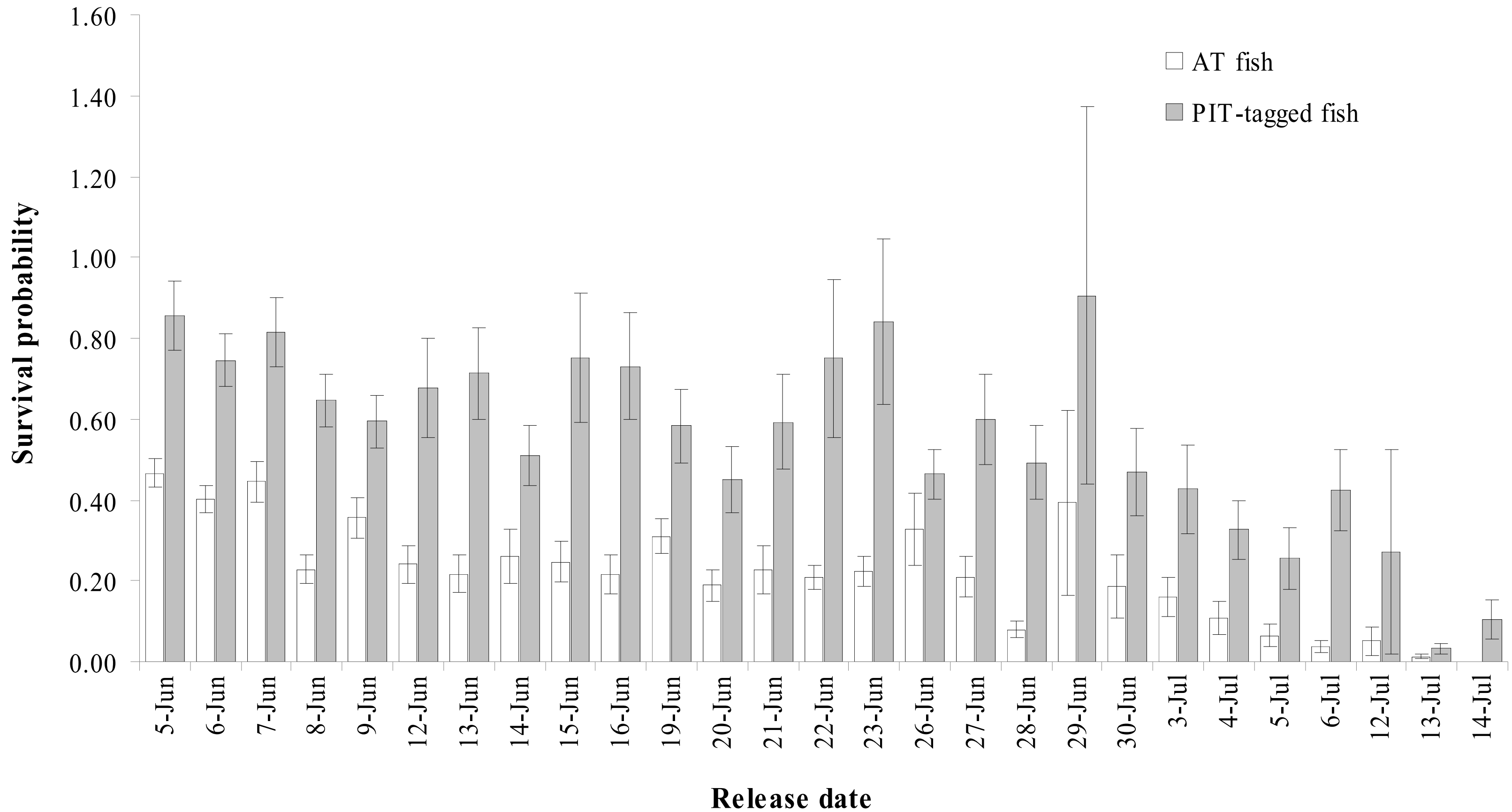


Figure 18. Survival probability of AT and PIT-tagged subyearling Chinook salmon from release at Lower Granite Dam to McNary Dam by release group in 2007. Error bars denote standard errors. For fish released on 14 July, the number of AT fish detected after release was too low to calculate an estimate.

Travel Time—As for yearling Chinook, overall mean travel time was calculated for each downstream detection site as the average of all group medians by tag type. For subyearling Chinook, overall mean travel time from release to each downstream detection site was significantly longer for AT than PIT-tagged releases ($P = 0.05$; Figure 19). These differences were as large as 1.2 d to Little Goose Dam ($P = 0.000$), 1.7 d to Lower Monumental Dam ($P = 0.009$), 5.2 d to Ice Harbor Dam ($P = 0.036$), and 2.7 d to McNary Dam ($P = 0.002$; Figure 19). Throughout the study period, a pattern of longer travel times for AT than PIT-tagged fish was apparent at most downstream sites.

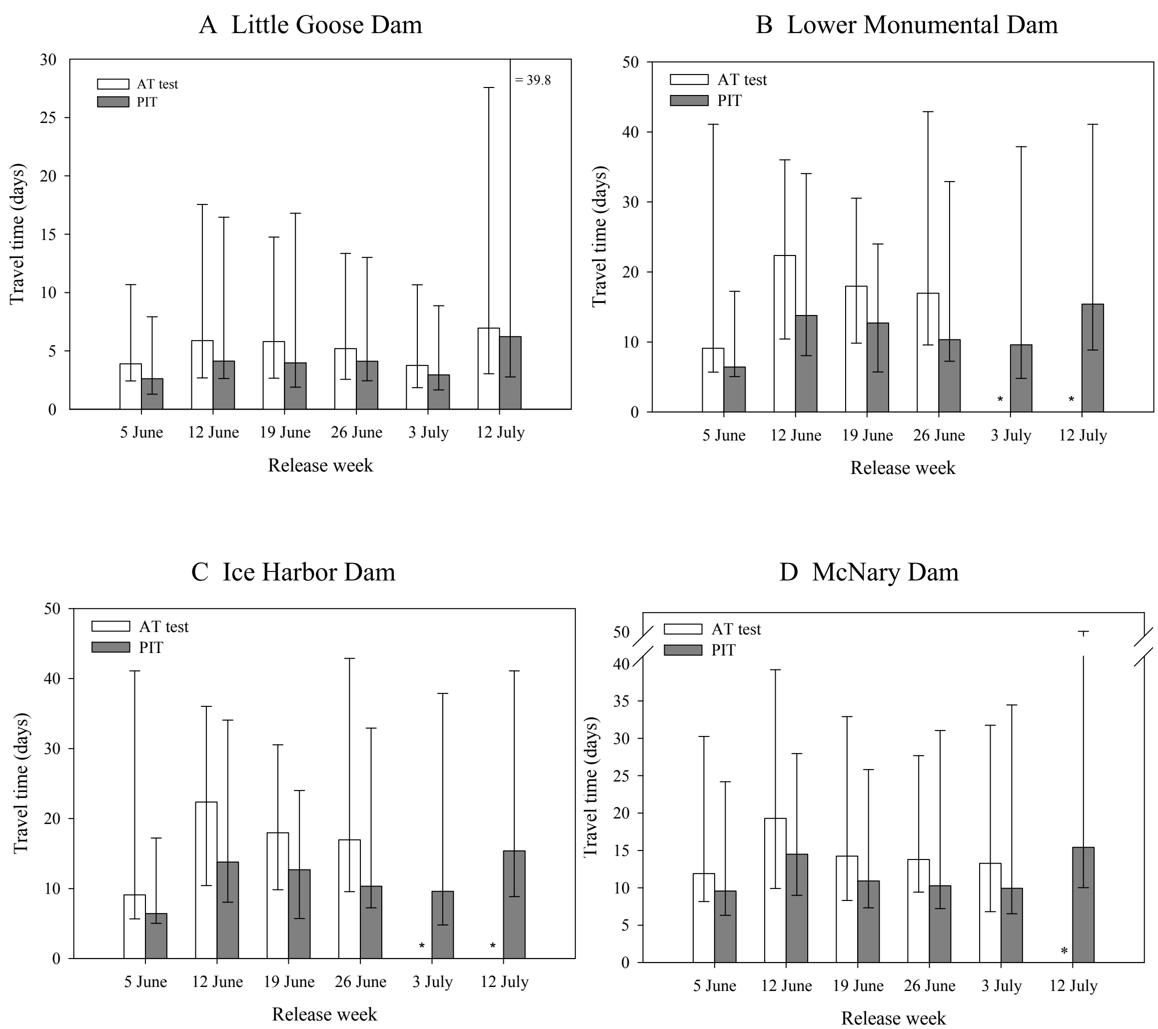


Figure 19. Median travel time of AT and PIT subyearling Chinook by week of release at Lower Granite Dam to detection at A) Little Goose B) Lower Monumental, C) Ice Harbor, and D) McNary Dams. Error bars represent 10th and 90th percentile of fish arriving at each detection location. Asterisks denote release groups where detections were too low to calculate an estimate.

Avian Predation—For subyearling Chinook released before 30 June, PIT-tag recovery from combined upriver bird colonies, averaged 1.3% (range 0.0-4.6%) for AT groups and 1.7% (range 0.2-2.5%) for PIT-tagged groups (Table 15). Upriver colonies sampled were the Badger Island pelican, Crescent Island gull and tern, Foundation Island cormorant, Miller Rocks gull, Miller Sands cormorant, and Rock Island tern colonies (Table 16). For subyearling Chinook released before 30 June, PIT-tag recovery from the estuarine tern and cormorant colonies on East Sand Island averaged 2.5% for AT groups (range 0.0-6.6%) and 2.0% for PIT-tagged groups (range 0.0-6.8%; Table 17).

Differences in the percent of PIT tags recovered from AT and PIT-tagged groups were not significant in recoveries from either the upriver ($P = 0.254$) or estuarine colonies ($P = 0.389$; Table 15). Percentages of PIT tags recovered by individual colony and location were similar between the two tag treatments (Table 16). These analyses were based on actual PIT-tag detections and were not expanded by detection efficiency rates. Because detection efficiencies are less than 100%, the estimates shown in Tables 15-17 represent minimum estimates of predation.

Table 15. Percentages of PIT tags from AT and PIT-tagged fish recovered on upriver and estuarine bird colonies in the Columbia River by date of release. Actual number of tags detected is reported in parentheses. NA denotes missing or incalculable values.

Release date	Upriver bird colonies	SE	Estuarine bird colonies	SE	Overall (from release)
			Acoustic-tagged fish		
5 June	3.4 (7)	1.3	4.2 (3)	2.5	3.8 (10)
6 June	3.9 (8)	1.4	1.0 (1)	1.0	3.4 (9)
7 June	4.6 (11)	1.4	2.7 (2)	1.9	4.9 (13)
8 June	0.4 (1)	0.4	0.0 (0)	NA	0.4 (1)
9 June	1.4 (3)	0.9	4.8 (3)	3.1	2.2 (6)
12 June	1.0 (2)	0.7	4.1 (3)	2.7	1.9 (5)
13 June	0.7 (1)	0.7	0.0 (0)	NA	0.4 (1)
14 June	0.5 (1)	0.5	4.4 (1)	4.4	0.6 (2)
15 June	0.3 (1)	0.3	3.2 (2)	2.9	0.9 (3)
16 June	1.0 (2)	0.7	4.2 (1)	4.3	1.1 (3)
19 June	0.5 (1)	0.5	1.9 (1)	2.0	0.6 (2)
20 June	1.3 (2)	0.9	0.0 (0)	NA	0.8 (2)
21 June	0.4 (1)	0.5	0 (NA)	NA	0.4 (1)
22 June	1.9 (4)	1.0	0.0 (0)	NA	1.3 (4)
23 June	1.1 (4)	0.7	0.0 (0)	NA	1.3 (4)
26 June	0.7 (1)	0.7	0.0 (0)	NA	0.3 (1)
27 June	0.5 (1)	0.6	4.4 (1)	4.4	0.8 (2)
28 June	0.8 (1)	0.9	4.1 (1)	5.2	0.7 (2)
29 June	0.9 (1)	0.9	6.6 (1)	6.6	0.8 (2)
30 June	0.0 (0)	NA	0.0 (0)	NA	0.0 (0)

Table 15. Continued.

Release date	Upriver Bird Colonies	SE	Estuarine Bird Colonies	SE	Overall (from release)
			Acoustic-tagged fish (continued)		
3 July	0.0 (0)	NA	NA (1)	NA	0.4 (1)
4 July	0.0 (0)	NA	0.0 (0)	NA	0.0 (0)
5 July	0.0 (0)	NA	NA (0)	NA	0.0 (0)
6 July	2.9 (2)	2.5	NA (0)	NA	1.5 (2)
12 July	0.0 (0)	NA	NA (0)	NA	0.0 (0)
13 July	3.8 (1)	4.2	0.0 (0)	NA	0.3 (1)
14 July	0.0 (0)	NA	0.0 (0)	NA	0.0 (0)
Overall	1.2 (56)	0.2	2.2 (21)	0.2	1.0 (77)
			PIT tagged fish		
5 June	1.7 (18)	0.4	3.1 (15)	0.9	3.0 (33)
6 June	1.7 (15)	0.4	2.2 (14)	0.7	2.5 (29)
7 June	2.5 (23)	0.5	2.1 (13	0.7	3.2 (36)
8 June	1.8 (16)	0.5	1.8 (12)	0.6	2.6 (28)
9 June	2.0 (17)	0.5	1.8 (10)	0.7	2.4 (27)
12 June	1.5 (15)	0.4	2.1 (13)	1.0	2.6 (28)
13 June	1.9 (20)	0.5	1.5 (10)	0.6	2.6 (30)
14 June	2.0 (21)	0.5	1.3 (7)	0.6	2.6 (28)
15 June	1.8 (13)	0.5	0.9 (5)	0.5	2.0 (18)
16 June	1.7 (17)	0.4	1.3 (9)	0.6	2.1 (26)
19 June	1.4 (18)	0.4	1.0 (11)	0.5	2.4 (29)
20 June	1.7 (12)	0.6	3.9 (9)	1.6	2.3 (21)
21 June	1.5 (10)	0.5	1.9 (4)	1.0	1.7 (14)
22 June	1.5 (9)	0.6	1.1 (4)	0.7	1.7 (13)
23 June	2.0 (15)	0.6	3.0 (12)	1.2	2.7 (27)
26 June	1.2 (13)	0.3	1.2 (6)	0.6	1.3 (19)
27 June	1.0 (8)	0.4	1.0 (5)	0.6	1.1 (13)
28 June	1.0 (7)	0.4	0.9 (5)	0.6	1.2 (12)
29 June	1.6 (3)	1.0	6.8 (3)	4.6	2.0 (6)
30 June	0.8 (4)	0.4	1.5 (2)	1.1	1.0 (6)
3 July	0.7 (5)	0.3	0.5 (3)	0.4	0.7 (8)
4 July	0.4 (3)	0.3	4.6 (8)	2.4	1.7 (11)
5 July	0.6 (2)	0.5	6.2 (5)	3.5	1.2 (7)
6 July	0.4 (5)	0.2	4.9 (14)	2.1	1.3 (19)
12 July	0.2 (1)	0.2	0.0 (0)	NA	0.1 (1)
13 July	0.2 (1)	0.3	NA (1)	NA	0.5 (2)
14 July	0.3 (1)	0.3	0.0 (0)	NA	0.1 (1)
Overall	1.4 (292)	0.1	2.0 (200)	0.2	1.9 (492)
			Mean difference (AT-PIT) through 29 Jun 2007		
Mean Difference	-0.3				0.5
SE	0.003				0.005
t	-1.18				0.88
P	0.254				0.389

Table 16. Percent of PIT tags recovered from upriver avian predator colonies by bird species and location, treatment, and release date. The actual number of tags recovered by colony is listed in parentheses.

Release date	Badger Island	Crescent Island			Foundation Island	Ice Harbor Tail	Miller Rocks	Miller Sands	Potholes	Rock Island
	Pelican	Gull	Mixed	Tern	Cormorant	Mixed	Gull	Cormorant	Tern	Tern
					Acoustic-tagged fish					
5 June	0.5 (1)	1.0 (2)	0.0 (0)	1.0 (2)	1.0 (2)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
6 June	0.0 (0)	0.0 (0)	0.0 (0)	2.0 (4)	2.0 (4)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
7 June	0.0 (0)	0.0 (0)	0.0 (0)	1.3 (3)	2.9 (7)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (1)
8 June	0.0 (0)	0.0 (0)	0.0 (0)	0.4 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
9 June	0.0 (0)	0.0 (0)	0.0 (0)	0.5 (1)	1.0 (2)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
12 June	0.0 (0)	0.0 (0)	0.0 (0)	0.5 (1)	0.5 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
13 June	0.0 (0)	0.0 (0)	0.0 (0)	0.7 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
14 June	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.5 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
15 June	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.3 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
16 June	0.5 (1)	0.0 (0)	0.0 (0)	0.5 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
19 June	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.5 (1)	0.0 (0)	0.0 (0)	0.0 (0)
20 June	0.6 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.6 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
21 June	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.4 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
22 June	0.0 (0)	0.5 (1)	0.0 (0)	0.9 (2)	0.5 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
23 June	0.3 (1)	0.5 (2)	0.0 (0)	0.3 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
26 June	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.7 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
27 June	0.0 (0)	0.0 (0)	0.0 (0)	0.5 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
28 June	0.0 (0)	0.8 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
29 June	0.0 (0)	0.0 (0)	0.0 (0)	0.9 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
30 June	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
3 July	0.0 (0)	0.0 (0)	0.7 (1)	0.7 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
4 July	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.4 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
5 July	0.0 (0)	0.7 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
6 July	0.0 (0)	1.4 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
12 July	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.8 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
13 July	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
14 July	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Overall	0.1 (4)	0.2 (8)	0.0 (1)	0.4 (20)	0.5 (21)	0.1 (3)	0.0 (1)	0.0 (0)	0.0 (0)	0.0 (1)

Table 16. Continued.

Release date	Badger Island Pelican	Crescent Island Gull	Crescent Island Mixed	Foundation Island Tern	Foundation Island Cormorant	Ice Harbor Tail Mixed	Miller Rocks Gull	Miller Sands Cormorant	Potholes Tern	Rock Island Tern
					PIT-tagged fish					
5 June	0.1 (1)	0.1 (1)	0.0 (0)	0.4 (4)	0.6 (6)	0.0 (0)	0.5 (5)	0.0 (1)	0.0 (0)	0.0 (0)
6 June	0.0 (0)	0.1 (1)	0.0 (0)	0.4 (4)	1.1 (10)	0.0 (0)	0.0)0)	0.0 (0)	0.0 (0)	0.0 (0)
7 June	0.0 (0)	0.1 (1)	0.0 (0)	0.5 (5)	1.4 (13)	0.0 (0)	0.4 (4)	0.0 (0)	0.0 (0)	0.0 (0)
8 June	0.1 (1)	0.1 (1)	0.0 (0)	0.4 (4)	0.8 (7)	0.0 (0)	0.2 (2)	0.0 (0)	0.0 (0)	0.0 (1)
9 June	0.0 (0)	0.3 (3)	0.0 (0)	0.5 (4)	0.9 (8)	0.0 (0)	0.2 (2)	0.0 (0)	0.0 (0)	0.0 (0)
12 June	0.0 (0)	0.0 (0)	0.0 (0)	0.5 (5)	0.3 (3)	0.0 (0)	0.7 (7)	0.0 (0)	0.0 (0)	0.0 (0)
13 June	0.1 (1)	0.2 (2)	0.0 (0)	0.8 (8)	0.3 (3)	0.0 (0)	0.6 (6)	0.0 (0)	0.0 (0)	0.0 (0)
14 June	0.1 (1)	0.2 (2)	0.0 (0)	1.1 (11)	0.2 (2)	0.0 (0)	0.4 (4)	0.0 (0)	0.1 (1)	0.0 (0)
15 June	0.0 (0)	0.1 (1)	0.0 (0)	0.7 (5)	0.6 (4)	0.0 (0)	0.4 (3)	0.0 (0)	0.0 (0)	0.0 (0)
16 June	0.1 (1)	0.3 (3)	0.0 (0)	0.8 (8)	0.2 (2)	0.0 (0)	0.2 (2)	0.0 (0)	0.0 (0)	0.0 (1)
19 June	0.0 (0)	0.1 (1)	0.0 (0)	0.7 (9)	0.3 (4)	0.0 (0)	0.2 (3)	0.0 (0)	0.0 (0)	0.0 (1)
20 June	0.0 (0)	0.3 (2)	0.0 (0)	0.9 (6)	0.4 (3)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)	0.0 (0)
21 June	0.0 (0)	0.1 (1)	0.0 (0)	0.7 (5)	0.3 (2)	0.0 (0)	0.3 (2)	0.0 (0)	0.0 (0)	0.0 (0)
22 June	0.0 (0)	0.2 (1)	0.0 (0)	0.5 (3)	0.3 (2)	0.0 (0)	0.5 (3)	0.0 (0)	0.0 (0)	0.0 (0)
23 June	0.0 (0)	0.0 (0)	0.0 (0)	0.5 (4)	0.9 (7)	0.0 (0)	0.4 (3)	0.0 (0)	0.0 (0)	0.0 (1)
26 June	0.2 (2)	0.3 (3)	0.0 (0)	0.6 (7)	0.1 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
27 June	0.3 (2)	0.1 (1)	0.0 (0)	0.4 (3)	0.0 (0)	0.0 (0)	0.1 (1)	0.0 (1)	0.0 (0)	0.0 (0)
28 June	0.0 (0)	0.3 (2)	0.1 (1)	0.4 (3)	0.0 (0)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)	0.0 (0)
29 June	0.0 (0)	1.0 (2)	0.0 (0)	0.5 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
30 June	0.0 (0)	0.4 (2)	0.0 (0)	0.2 (1)	0.2 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
3 July	0.1 (1)	0.3 (2)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)	0.0 (0)
4 July	0.1 (1)	0.0 (0)	0.0 (0)	0.1 (1)	0.1 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
5 July	0.0 (0)	0.0 (0)	0.0 (0)	0.6 (2)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
6 July	0.0 (0)	0.1 (1)	0.0 (0)	0.2 (2)	0.1 (1)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)	0.0 (0)
12 July	0.0 (0)	0.0 (0)	0.0 (0)	0.2 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
13 July	0.0 (0)	0.0 (0)	0.0 (0)	0.2 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
14 July	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.3 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Overall	0.1 (11)	0.2 (33)	0.0 (1)	0.5 (108)	0.4 (81)	0 (0.0)	0.2 (51)	0.0 (2)	0.0 (1)	0.0 (4)

Table 17. Percentage of AT and PIT subyearling Chinook salmon by release date with PIT tags recovered on East Sand Island tern and cormorant colonies. Numbers of tags recovered are shown in parentheses.

	Percentage (%) and number (n) of PIT tags found on East Sand Island From AT and PIT subyearling Chinook salmon			
	Cormorant		Tern	
Release date	AT fish	PIT-tagged fish	AT fish	PIT-tagged fish
5 June	1.0 (1)	0.8 (4)	2.8 (2)	2.3 (11)
6 June	0.0 (0)	0.5 (3)	1.0 (1)	1.7 (11)
7 June	0.0 (0)	0.3 (2)	2.7 (2)	1.7 (11)
8 June	0.0 (0)	0.6 (4)	0.0 (0)	1.2 (8)
9 June	1.4 (1)	0.0 (0)	3.2 (2)	1.8 (10)
12 June	6.3 (2)	0.0 (0)	1.4 (1)	2.1 (13)
13 June	0.0 (0)	0.3 (2)	0.0 (0)	1.2 (8)
14 June	0.0 (0)	0.6 (3)	4.4 (1)	0.7 (4)
15 June	0.0 (0)	0.0 (0)	3.3 (2)	0.9 (5)
16 June	0.0 (0)	0.0 (0)	4.2 (1)	1.3 (9)
19 June	0.0 (0)	0.3 (3)	1.9 (1)	0.7 (8)
20 June	0.0 (0)	0.0 (0)	0.0 (0)	3.9 (9)
21 June	0.0 (0)	0.9 (2)	0.0 (0)	0.9 (2)
22 June	0.0 (0)	0.0 (0)	0.0 (0)	1.1 (4)
23 June	0.0 (0)	0.2 (1)	0.0 (0)	2.7 (11)
26 June	0.0 (0)	0.4 (2)	0.0 (0)	0.8 (4)
27 June	0.0 (0)	0.0 (0)	4.4 (1)	1.0 (5)
28 June	0.0 (0)	0.3 (2)	4.1 (1)	0.5 (3)
29 June	0.0 (0)	2.3 (1)	6.6 (1)	4.6 (2)
30 June	0.0 (0)	0.0 (0)	4.5 (1)	1.5 (2)
3 July	0.0 (0)	0.0 (0)	0.0 (0)	0.5 (3)
4 July	0.0 (0)	0.0 (0)	0.0 (0)	4.6 (8)
5 July	0.0 (0)	1.2 (1)	0.0 (0)	5.0 (4)
6 July	0.0 (0)	1.7 (5)	0.0 (0)	3.1 (9)
12 July	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
13 July	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (1)
14 July	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Overall	0.4 (40)	0.3 (35)	1.8 (17)	1.6 (165)

Discussion

Detection probabilities for PIT-tagged fish in this study are estimates of the proportion of migrating fish guided into the facility bypass system at a dam and electronically detected. Detection probabilities can vary among locations, over time at the same location, and between populations of fish. Successful fish guidance varies according to factors such as the type of equipment and engineering utilized at a particular facility, daily operations (e.g., the amount of spill that is occurring at the time of fish passage), and environmental conditions such as flow, turbidity, and debris load in the water column.

Guidance efficiencies can also vary depending on the behavior and physiological condition of migrating fish (Giorgi et al. 1988; Gessel et al. 1991). Once fish have entered a bypass system, detection efficiency can vary depending on the configuration of fish with respect to monitors (proximity and angle), number of monitors at the project, turbulence during fish passage, electromagnetic interference, project hydraulics, antenna shield designs, and fish density (Stein et al. 2004).

For yearling Chinook salmon, considerable variability in mean detection probability was observed among detection sites. This variability was likely due in part to a combination of the aforementioned variables and was to be expected. Additionally, we observed differences in detection probabilities between treatment groups for fish that had been released simultaneously. Acoustic-tagged fish were more likely to be detected at Little Goose Dam, and PIT-tagged fish were more likely to be detected further downstream at McNary and Bonneville Dams. Differences in mean detection probability between groups were relatively small (0.03 for the three sites). However, the continued pattern may indicate either that behavior differed as fish approached the dam, or that the ability of fish to be detected once in the bypass system differed depending on treatment (e.g. due to differential tag loss).

For most release pairs and detection locations, travel time differences between treatment groups were fairly small. Therefore, we assumed that treatment groups were experiencing similar environmental conditions as they migrated downstream. The only significant difference in travel time between the two treatment groups (0.5 d) was observed at John Day Dam, where we observed no significant difference in detection probability.

Subtle differences in behavior between treatment groups could have contributed to the observed differences in detection probability. For example, vertical position in the water column might differ between AT and PIT-tagged fish due to variable depth compensation abilities between tag treatments. The ability to compensate at depth might vary due to differential tag burden or to a more complex causality such as reduced fitness in one of the groups. Perry et al. (2001) observed that changes in depth/pressure affected buoyancy to a greater extent in fish implanted with dummy radio transmitters (minus a trailing antenna) than in control fish. Based on these observations, they cautioned that tagged fish may expend more energy swimming in order to maintain buoyancy at depth compared to non-tagged fish, or tagged fish might travel at shallower depths in order to compensate for the higher costs of maintaining neutral buoyancy.

However, if behavioral differences were the only factor driving the observed differences in detection probability, one would expect that the direction of these differences would have been consistent throughout the system. This was not the case in the spring; therefore additional factors likely influenced detection probabilities, specifically the switch from higher detection probability in AT fish shortly after release to a higher probability in PIT-tagged fish lower in the river. These factors include simple random variation, bias in our analysis, and progressive loss of PIT tags in AT fish as they migrated downstream.

In our analysis, the PIT-tag detection probabilities of AT fish were adjusted downward for locations where an AT fish with no PIT detection was later detected on an acoustic node downstream. For all downstream locations except Lower Monumental Dam, detection probabilities for AT fish were adjusted down (and survival estimates up). A similar adjustment for tag loss was not possible for PIT-tagged fish. Therefore, if true tag loss in PIT-tagged fish was more than 0.0% and was similar between the two treatments (or higher in PIT-tagged fish), these corrections would have produced detection probabilities at both McNary and Bonneville Dams that were biased upward for PIT-tagged fish (so survival estimates for PIT-tagged fish would have been biased low). For comparison, the non-adjusted data showed mean detection probabilities 5% higher for AT fish at Little Goose ($P = 0.002$), and 7% higher for AT fish at Bonneville Dam ($P = 0.002$). At McNary Dam there was no difference between treatments using the non-adjusted data.

However, there is little reason to suspect that this bias occurred, because tag loss for PIT tags is known to be negligible. In the extended holding study (reported here), observed tag loss in PIT-tagged fish was only 0.3%, while PIT-tag loss in AT fish was 2.0%. Based on these observations, it is more likely that subtle behavioral differences between the two treatment groups influenced detection probabilities early in the migration and that differences in PIT tag loss (AT > PIT-tagged fish) may have influenced detection probabilities further downstream.

Our observation of different survival between AT and PIT-tag treatments for yearling Chinook was similar to findings from the radiotelemetry studies of Hockersmith et al. (1999, 2003) in that the differences appeared to develop over time and distance from release. Acoutic-tagged fish frequently had higher survival than PIT-tagged fish in the Snake River, but consistently had lower survival in the Columbia River. Mean tag burden by weight was similar between our study (3.5%) and the study of Hockersmith et al. (2003) (3.9%, range 1.3-7.0)

In their work comparing JSATS and PIT tag effects during 2006, Hockersmith et al. (2007b) found slightly higher survival for acoustic-tagged than PIT-tagged fish in the Snake River, but slightly lower survival for AT fish further downstream, in the Columbia River. Significantly higher survival was found for acoustic tagged fish only over the 60-km reach from release to Little Goose Dam. Similar to Hockersmith et al. (2007b), we observed a trend of higher survival for AT fish at two Snake River Dams but higher survival for PIT-tagged fish at Columbia River Dams. Significant differences in Snake River survival were found only at Lower Monumental Dam at the 0.080 level, while differences in Columbia River survival were found at McNary Dam at the 0.054 level as well as at John Day (P = 0.010) and Bonneville Dam (P = 0.001).

Unfortunately, the tag comparison work of Hockersmith et al. (2007b) suffered from low sample sizes of AT fish, with far fewer replicates than were called for by the study design. The larger samples of AT fish tagged in 2007 imparted more power to this study for identifying differences between treatments. A further increase in numbers of AT releases appears warranted if greater test sensitivity is to be obtained in future studies.

Other recent field studies have been conducted on the Columbia River to compare survival between acoustic and PIT-tagged fish (Skalski et al. 2003, 2005) and have reported no difference in survival between the two groups. In these studies, the distance over which potential tag effects were measured was approximately 100 km or less. Although we observed comparatively higher survival in AT fish over a distance of 106 km, for PIT-tagged fish, we observed higher survival rates only over distances of 200 km or more. Acoustic-tagged yearling Chinook used in our study were smaller than those used by Skalski et al. (2003, 2005). However, mean tag burden by weight of our fish (3.5%) was within the range reported by Skalski et al. in 2003 (2.7-4.0%) and slightly larger than the mean reported in 2005 (2.5%).

Potential relationships between relative tag effects and size (length) of fish at the time of tagging are in need of further analyses. Preliminary results suggest that relative survival (AT/PIT) was likely lower for smaller fish in 2007 (S. Smith, NMFS, personal communication). Although length and weight relationships between survival and tag burden have been explored during previous laboratory studies (Brown et al. 2007b; Lacroix et al. 2004; Moore et al. 1990), the results have been mixed and complicated in some cases by AT tag loss. Furthermore, acoustic-tagged fish in this study fared better in the laboratory than in the river, suggesting that laboratory studies overall may not adequately represent the experience of fish migrating in the Columbia River Basin.

Covariate analyses are needed to investigate potential relationships of environmental and biological factors with survival estimates (i.e., tag effects). Data suggest a trend in survival over time that may be related to environmental parameters such as flow or time of release. At McNary Dam, for example, mean relative survival AT/PIT for inriver migrating fish was 0.89 for fish released through 5 May and 1.00 for fish released during 9-15 May.

Initial covariate analyses (see Appendix F) indicated that relative survival to McNary Dam was associated with tag burden, fork length, condition factor, water temperature, and river discharge. Survival of AT fish relative to PIT-tagged fish decreased with increasing tag burden but increased with increasing fork length, condition factor, water temperature, and river discharge. However, the multivariable analyses demonstrated strong multi-co-linearity among predictor variables, making interpretation of the regression analysis difficult.

Other statistical techniques may be capable of clarifying these relationships. Model estimates using data sets of the size and complexity produced here are extremely computation-intensive, and surpassed the limits of our software (SURPH/MARK). Fitting these data involves co-variables at both the tag-group level (e.g. flow exposure) and individual level (e.g. length at tagging), and can take hours even on powerful computers. Analyses of 2007 data were delayed in part because of this difficulty. When 2008 data became available before analyses of 2007 data were complete, we determined that these important analyses would benefit greatly from an additional year of data. Analyses of 2007-2008 data will be reported when complete (S. Smith, NMFS, personal communication). These analyses may provide data on which to base more predictive statements about tag effects.

Results from analyses of detection probability and relative survival indicated that AT fish were not likely behaving in the same manner or surviving at the same rates as PIT-tagged fish. However, results from analysis of relative predation suggested that AT fish were no more vulnerable to avian predators than the PIT-tagged fish as they migrated through the upper river and estuary.

Similar to findings for the yearling fish, successful PIT-tag detection of subyearling Chinook was dependent on two factors: guidance into the bypass system and subsequent electronic detection. These factors in turn were dependant on several environmental and biological variables, which would be expected to vary between detection sites as well as to vary temporally at the same site.

Unlike the comparisons observed for yearling Chinook, mean travel times for subyearling Chinook differed significantly at most downstream detection sites. The AT fish groups needed significantly more time than PIT-tagged groups to reach all detection sites on the Snake River. This discrepancy in rate of travel suggests that AT and PIT-tagged fish may have been exposed to different environmental conditions as they approached each project bypass system. This dissimilarity alone could explain the difference in detection probability observed between AT and PIT-tagged fish at Little Goose Dam. Alternative explanations would potentially include behavioral differences between the two treatment groups and differential tag loss (PIT>AT) between groups. We attribute the low detection numbers of AT fish below McNary Dam and of AT pilot fish at all locations to mortality.

Although behavior was not directly examined, significant differences in travel time to Little Goose, Lower Monumental, Ice Harbor, and McNary Dam suggested that AT and PIT-tagged fish were not migrating downstream in exactly the same manner. Possible behavioral difference was also indicated by different rates of survival to Little Goose and McNary Dam. Lower survival of AT fish to Little Goose Dam may indicate that at least a component of the AT fish approaching this detection site was less fit than their PIT-tagged counterparts. A fish that was moribund would likely be slower or less direct in its swimming and may have difficulty maintaining neutral buoyancy at depth compared to a healthy fish.

Similar to the yearling groups, we also observed differential tag loss between treatment groups in subyearling fish held in the laboratory for 90 d (AT>PIT), although the direction of this difference was not consistent with the higher detection probability observed at Little Goose for AT fish. Also similar to yearling fish, detection probability estimates were adjusted down at both Little Goose and McNary Dams for AT fish when downstream AT detections were considered. If PIT-tag loss in the field was >0% but similar between the two treatments, or higher in the PIT tagged fish, then these adjustments may have obscured even larger differences in detection probability between the two groups.

Differences in relative survival (PIT>AT) were more pronounced and manifest closer to the point of release for subyearling than for yearling Chinook treatment groups. There also appeared to be a trend in relative survival of subyearling Chinook over time, with larger differences between treatments observed later in the migration. Mean relative survival (AT/PIT) to McNary Dam was 0.42 for subyearling groups released before 25 June and 0.33 for those released after.

While river flow in the Snake and Columbia Rivers tends to increase over time during spring, the opposite occurs during summer. As flow decreases, water temperature typically increases. Not surprisingly, both of these environmental trends were observed during the 2007 subyearling migration season. Flow measured at Lower Granite Dam exhibited a fairly steady decline from 4 June to 13 July (56.25 to 33.12 kcfs), while water temperature remained fairly constant until 25 June, fluctuating from 15.6 to 17.2°C.

Temperature increased to 19.4°C on 26 June and eventually peaked and remained elevated above 20°C from 6 to 10 July. Timing of riverine temperature spikes coincided with the increase in differential survival observed in the subyearling release groups.

The idea that relatively high tagging temperatures will adversely affect survival and tag retention in surgically tagged fish is not novel, and the effects of temperature have been reported by others (Bunnell and Isely 1999; Knights and Lasee 1996; and Walsh et al. 2000). Chinook salmon are poikilotherms, and as such their metabolism increases as the environment warms. As metabolic rates go up, oxygen consumption rates increase, and stressors such as handling, holding, and anesthesia are more likely to compromise these fish (Noga 1996). This is of particular concern when tagging is conducted at a time when the river itself is becoming more active biologically (e.g. bacteria and parasites are reproducing quickly), and piscivorous predators such as Northern pikeminnow, bass, and catfish are also becoming more active (Vigg and Burley 1991; Tabor 1993).

Smith et al. (2003) reported similarly strong correlations between survival and water temperature, river discharge, and water transparency in relation to a PIT-tagging study. Unfortunately, due to the fact that all three of these variables were highly correlated with each other, they were unable to determine which most influenced survival. Our initial covariate analyses (Appendix F) performed on the 2007 data were similarly inconclusive, mostly due to co-linearity among explanatory factors such as release date, river discharge, water temperature, and mean size of fish released.

Potential relationships between relative tag effects and size (length) of fish at the time of tagging are also being explored. Certainly, a rudimentary comparison between the number of downstream detections of PIT-tagged, AT pilot, and AT fish suggests that size at tagging played a role in survival on some level. Preliminary results also suggest that relative survival (AT/PIT) is likely lower for smaller fish within the AT group. As described above, techniques to clarify all of these relationships are being applied to data from both 2007 and 2008 (S. Smith, NMFS, personal communication). When 2 years of data analysis are complete, we expect to have a more reasonable foundation on which to base predictive statements about tag effects.

Similar to the yearling Chinook salmon groups, results from the comparative avian predation analysis suggested that subyearling AT fish were no more vulnerable to avian predation than PIT-tagged fish as they migrated through the upper river and into the estuary.

GROSS NECROPSY AND HISTOLOGICAL EVALUATIONS OF MIGRATING JUVENILE SALMON

Executive Summary

Yearling Chinook Salmon. To provide insight into the mechanism responsible for any tag effects observed, we subsampled study fish at two downstream sites for necropsy and histological evaluation. Up to 10 yearling Chinook salmon from each tag treatment and each temporal group were recaptured during migration using the separation-by-code (SbyC) systems at McNary and Bonneville Dam. A total of 75 AT and 89 PIT-tagged fish were recaptured at McNary Dam, while 64 AT and 79 PIT-tagged fish were recaptured at Bonneville Dam. We did not meet target collection numbers for either group. Recaptured fish were euthanized and examined for tag loss, disease, and histological change due to tag implantation. Kidney tissue samples were also collected and examined for the antigen to *Renibacterium salmoninarum* (Rs), the causative agent of bacterial kidney disease (BKD). A group of 30 non-tagged reference fish was used to provide baseline data for comparisons of gross necropsy, histological evaluation, and assessments of BKD antigen in AT and PIT-tag treatment fish. Reference fish were taken from hatchery yearling Chinook collected at Lower Granite Dam for evaluations of migration behavior and survival.

For both tag treatments, gross necropsy revealed less ceacal fat in fish collected at McNary and Bonneville Dam than in reference fish. Caecal fat was slightly higher in PIT-tagged fish than AT fish collected at McNary and was rated similarly between tag treatments for fish recaptured at Bonneville Dam. Mesenteric fat content was also rated lower in fish from both tag treatments and both dams than in reference fish. Mesenteric fat was higher in PIT than AT fish recaptured at both McNary and Bonneville Dam. Splenic engorgement/enlargement was more prevalent in treatment fish of both tag types than in reference fish. Enlarged spleens were observed in a higher percentage of fish collected at McNary than at Bonnville Dam. Splenic enlargement was observed at a similar rate for both tag treatments in fish from McNary Dam and at a higher rate for AT than PIT-tagged fish in fish from Bonneville Dam.

The percentage of fish observed with food in the stomach increased for both treatment groups from McNary to Bonneville Dam. In subsamples from both dams, PIT-tagged fish had a higher percentage of individuals with food in the stomach than AT fish. Kidney abnormalities were more prevalent in fish recaptured at the downstream dams than in reference fish, but were equally prevalent between the two tag treatments. Liver abnormalities were more prevalent in fish recaptured at both downstream dams than in fish from Lower Granite Dam, and more prevalent in AT than in reference or PIT-tagged fish. Among the gross necropsy comparisons, the only significant difference observed between tag treatments ($\alpha \leq 0.10$) was a greater proportion of liver discoloration in AT than PIT-tagged fish recaptured at Bonneville Dam ($P = 0.095$).

Comparative histopathology metrics varied by recapture site and were mixed with respect to nutritional indicators, with some being higher in AT and others in PIT-tagged fish. Nutritional indicators included liver vacuolation, pancreatic zymogen, pancreatic atrophy, mesenteric adipose, lower intestinal and pyloric caecae mucosal glycogen, and intestinal digesta presence. However, histological indicators of inflammation and healing showed a consistent pattern of higher inflammation and slower healing in AT than PIT-tagged fish. For example, chronic peritonitis was higher in AT than PIT-tagged fish at Bonneville ($P = 0.003$) and McNary Dam ($P = 0.042$). Poor apposition of the incision was also more common in AT than PIT-tagged fish at both dams ($P = 0.000$ for both). Reknitting of the stratum compactum was significantly more prevalent in PIT-tagged fish at McNary Dam ($P = 0.002$), and significantly more prevalent in PIT-tagged fish at Bonneville Dam at the 0.054 level. Incision adhesions were significantly higher in AT than PIT-tagged fish at McNary Dam ($P = 0.008$), as was splenic congestion, an indicator of stress ($P = 0.027$). Incision closure was more prevalent in PIT than AT fish at Bonneville Dam ($P = 0.011$), and incision chronic inflammation severity was rated higher in AT than PIT ($P = 0.001$) at this location.

For yearling Chinook, two significant notable trends were observed in the histology comparisons among size bins composed of both tag treatments combined. At McNary Dam, mesenteric adipose was greater in larger fish (14-16 >13 >11-12 cm; $P < 0.050$); at Bonneville Dam, poor incision apposition was observed more often in smaller fish (11-12 > 13, 14, 15-16 cm; $P = 0.006$).

Rs antigen levels were evaluated using enzyme-linked immunosorbent assay. For hatchery yearling Chinook, Rs antigen levels ranged from 0.070 to 0.131 in reference fish, 0.07 to 0.133 for fish of both tag treatments recaptured at McNary Dam, and 0.068 to 0.298 for fish of both tag treatments recaptured at Bonneville Dam (with two others at 0.463 and 1.613). Since Rs antigen levels were low for all but a few fish, no further analyses were conducted to evaluate differences among collection sites or tag treatments.

Subyearling Chinook Salmon. For subyearling Chinook salmon, up to 10 fish from each release and treatment combination were targeted for recapture using the SbyC system at Bonneville Dam. The SbyC system at McNary Dam was not operating during the study period, so no subyearling study fish could be recaptured. A total of 9 AT, 0 AT pilot, and 71 PIT-tagged fish were collected at Bonneville Dam throughout the summer sampling period. We did not meet our target collection goals for any of the three treatment groups. After recapture, fish were euthanized and examined for tag loss, disease, and histological changes due to tag implantation. A group of 79 non-tagged reference fish were necropsied in the same manner as tagged fish to provide baseline data for comparison. Reference fish were taken from collections of wild and hatchery subyearling Chinook at Lower Granite Dam.

Gross necropsy of reference fish collected at Lower Granite Dam and of treatment fish recaptured at Bonneville Dam revealed some trends among study groups. In general, less caecal fat was observed in fish belonging to both tag treatment groups collected at Bonneville Dam compared to reference fish, and PIT-tagged fish tended to have more caecal fat than AT fish. Similar trends were observed with respect to mesenteric fat content. Liver and kidney discoloration and or abnormalities were more prevalent in fish recaptured at Bonneville Dam than in reference fish, and more prevalent in AT than PIT-tagged fish. However, due to very small sample sizes (N = 9 for the AT group), no definite conclusions could be made based on statistical analysis of the gross necropsy data. None of the gross necropsy comparisons differed significantly.

Results from comparative histopathology analyses between tag treatments showed significant differences in 5 of 43 metrics evaluated in subyearling Chinook recaptured at Bonneville Dam ($\alpha = 0.05$). One additional metric was significant at $\alpha = 0.10$. The majority of the differences occurred in indicators related to inflammation at the site of the incision and healing. Mesenteric chronic inflammation severity was significantly higher in AT fish at the 0.075 level, and chronic inflammation at the incision was significantly more severe in AT fish ($P = 0.011$). For AT subyearling fish, chronic peritonitis and dermal hemorrhage/fibrin were also significantly higher ($P = 0.007$ and $P = 0.009$ respectively). Healing at the incision/injection site was significantly greater in the PIT-tagged fish ($P = 0.001$).

For recaptured fish from both tag treatments, a pattern was found across size bins for the presence/absence of liver lymphocytic infiltrates. These inflammatory cells were observed more often in smaller fish (9-10, 11 cm > 12-13 cm; $P = 0.090$), and mesenteric adipose was higher in larger fish (12-13 cm > 9-11 cm; $P = 0.033$). Myxosporea in the kidney tubules were observed more often in fish belonging to the 9-10 cm than 11, and 12-13 cm bins, and this difference was significant at the 0.092 level. Incision adhesions were observed more often in larger fish (12-13> 9-10, 11 cm; $P = 0.057$).

Rs antigen levels, as measured by ELISA, ranged from 0.070 to 0.213 in reference fish and from 0.078 to 0.442 in fish of both tag types recaptured at Bonneville Dam. Of 70 samples, Rs antigen levels exceeded 0.299 in only 2. Because values for all but a few fish were considered low, no further analyses were conducted.

Introduction

Numerous laboratory studies have examined the physiological effects of surgical tagging (Brown et al. 2007a; Knights and Lasee 1996; Liedtke et al. 2007; Marty and Summerfelt 1986, 1990; Walsh et al. 2000). Nevertheless, it is imperative to examine tagged fish after release to the field, where impacts of a given tagging procedure and/or tag can be manifested outside of the more forgiving laboratory environment. Toward this end, we recaptured and examined fish from each tag treatment at two downstream locations along the migration route. Through this diagnostic work, we also hoped to gain insight into the potential mechanism(s) responsible for any tag effects observed. Necropsy data collected at the time of tagging were used to establish baseline fish condition and to rule out pre-existing infectious or idiopathic disease that might have affected fish performance or survival.

Methods

Fish Collection

During spring and summer 2007, study fish were collected at Lower Granite Dam for evaluation of AT vs. PIT tag effects on behavior and survival. From these collections, we set aside 30 non-tagged hatchery yearling Chinook salmon in spring and 79 non-tagged subyearling Chinook (wild and hatchery) in summer. These groups were used as reference fish to provide baseline data for evaluations of tag effects from gross necropsy and assessment of BKD prevalence. No reference group was needed for the histological evaluations because their purpose was to determine the causes of any potential differences observed between the two tag treatments.

Treatment fish for gross necropsy, histological examination, and assessment of BKD were subsamples of AT- and PIT-tagged yearling and subyearling Chinook replicates tagged and released at Lower Granite Dam for migration behavior and survival studies. Actively migrating AT- and PIT-tagged fish were recaptured using the SbyC systems at McNary and Bonneville Dam; these systems allow PIT-tagged fish to be selectively recaptured based on their PIT-tag code (PSMFC 1996). Yearling and subyearling release groups were collected, examined, and analyzed separately.

Yearling Chinook treatment fish were divided into 20 unique groups based on release date (10 dates) and tag treatment (AT or PIT). The SbyC systems at both downstream dams were programmed to collect the first 10 fish detected from each group, for a maximum of 200 recaptures at each downstream dam (10 fish/group × 2 tag treatments × 10 release groups).

For subyearling Chinook, we followed a similar protocol after first pooling consecutive release groups to reduce the number of groups from 27 to 13. Reducing the number of recapture groups facilitated coordination of separation-by-code actions among personnel from various agencies at the dams. Fewer target groups also helped to ensure adequate sample sizes among the three tag treatment groups (AT, AT pilot, and PIT). In total, 39 unique groups of subyearling Chinook were targeted for SbyC diversion at Bonneville Dam (10 fish/group × 3 treatment groups × 13 release groups). The SbyC system was not operational at McNary Dam during the subyearling study period, so recaptures could not be taken from this location.

Targeting the first 10 fish from each release/treatment may have biased recapture samples in favor of the 10 healthiest or strongest fish from each group. However, this protocol also provided for minimal collection impacts on study fish and bycatch, as well as consistent, systematic programming instructions for the SbyC systems.

At McNary Dam, we successfully recaptured a total of 169 hatchery yearling Chinook (75 AT and 89 PIT-tagged fish). At Bonneville Dam, we recaptured 144 hatchery yearling Chinook (64 AT and 79 PIT) and 80 subyearling Chinook (9 AT and 71 PIT). We did not meet our target sample size for any of the treatment groups (yearling and subyearling fish). Treatment fish were sacrificed immediately after recapture, and reference fish were sacrificed immediately after collection.

Variability in sample size between tag treatments may have resulted from unequal release numbers between treatment groups, differential survival, dissimilar routes of passage, or a combination of these variables.

Necropsy and Tissue Collection

Upon recapture in the SbyC system, study fish were humanely euthanized with an overdose of MS-222 (UFR Committee 2004). Each fish was measured, weighed, and evaluated for external abnormalities and gross visible injury, such as lesions, descaling, or hemorrhaging. Necropsies were performed on each fish in the manner of Noga (1996). Fish were examined for gross tissue response to tagging, such as tag encapsulation. The following metrics were evaluated using a Goede index scoring system (Goede and Barton 1990): smolt index, eyes, fins, gills, pseudobranchs, caecal fat, mesenteric fat, spleen, food in stomach, hind gut, liver, gall bladder, sex, and kidney. A description of the numeric scale used to evaluate each metric is presented with the results. Goede index scores were compared between treatments at each collection site (yearling and subyearling fish) using Kruskal-Wallace non-parametric tests (Hollander and Wolfe 1979).

Along with gross necropsy records, tissue samples for histological examination were taken from the gill, heart, liver, head kidney, trunk kidney, spleen, upper intestine, lower intestine, skin in area of the incision/suture, and pyloric ceca. Tissues for histology were placed into one of three separate cassettes labeled gill (gill), soft tissue (heart, liver, head and trunk kidney, spleen, upper and lower intestine and pyloric ceca), and incision (skin in area of incision/suture). All tissue samples were place directly into Davidson's solution for fixation and left undisturbed for 7-14 d.

After fixation, tissue samples were rinsed with distilled water and transferred to 70% ethyl alcohol for continued preservation until they were processed further. Fixed tissues were dehydrated, processed using a Shandon Hypercenter XP automated tissue processor, and embedded in Polyfin (Triangle Biomedical Sciences). Tissues sections (4-5µm thick) were stained with haematoxylin and eosin-phloxine (Luna 1968) and examined by light microscopy at the Ecotoxicology and Environmental Fish Health Program laboratory of the Northwest Fisheries Science Center in Seattle, WA (Appendix E lists specific indices evaluated under microscopy, as well as the scale used for scoring each index).

Histological Analyses

Fish used for histological analyses were the same migrating tag-treatment fish recaptured in the SbyC systems at Bonneville and McNary Dam for yearling Chinook and in the SbyC at Bonneville for subyearling Chinook. Reference fish were the same fish taken at the time of tagging at Lower Granite Dam (anesthetized but not tagged).

Tissue samples were evaluated using 42 histological metrics for yearling and 43 metrics for subyearling fish: five metrics were scored on an ordinal scale of 0 to 3, two on an ordinal scale of 0 to 7, two on an ordinal scale of 1 to 7, and the remainder scored by presence/absence (Appendix E). After all tissue samples were evaluated, scores were coded and entered into a spreadsheet, and data were compared by treatment group, at each collection location using chi-square contingency tables, Fisher's exact test (presence/absence data), or Kruskal-Wallace non-parametric tests (ordinal data; Hollander and Wolfe 1973).

Tag treatment fish were also compared by size class at each collection location. For these analyses, yearling Chinook were combined regardless of treatment, sizes were rounded to the nearest 1 cm and fish were binned into groups of 11-12, 13, 14, and 15-16 cm. Subyearling AT and PIT-tagged fish were also combined at Bonneville Dam and similarly binned into groups (9-10, 11, and 12-13 cm) to increase sample sizes and create comparable samples between tag treatments.

Table 18. Size bins used for yearling and subyearling Chinook histological analyses.

	Yearling Chinook size (cm)			
	11-12	13	14	15-16
AT (N)	37	58	34	7
PIT (N)	43	53	43	18
Total	80	111	77	25
	Subyearling Chinook size (cm)			
	9-10	11	12-13	
AT (N)	6	1	2	
PIT (N)	23	27	9	
Total	29	28	11	

Prevalence of *Renibacterium salmoninarum*

Kidney tissue samples were also collected from each sampled and recaptured fish at the time of necropsy and examined for the antigen to *Renibacterium salmoninarum* (Rs), the causative agent of bacterial kidney disease (BKD). Fresh kidney samples were excised and placed into individually labeled sample bags (Nasco Whirlpak, 2 oz, #B01064). Samples were frozen and transported on ice to the Northwest Fisheries Science Center. In the laboratory, kidney samples were thawed, diluted 1:4 (w/v) in 0.01-M phosphate-buffered saline with 0.05% Tween 20, homogenized using a print roller, and then frozen in screw cap tubes.

For each treatment and release group combination, the Rs antigen was determined based on enzyme-linked immunosorbent assay (ELISA) as described by Pascho and Mulcahy (1987) and modified by Pascho et al. (1991). Coating and conjugate antibodies (Kirkegaard and Perry Laboratories, Gaithersburg MD) were used at dilutions of 1:1500 and 1:4000 respectively. Optical densities were read at 405 nm using an automated 96-well plate reader (Model ELx808 IU, Bio-Tek Instruments, Winooski, VT). Negative controls and blanks, as well as substrate and conjugate controls, were run for each assay. ELISA values were reported as absolute readings, without subtracting values for blanks or negative controls.

Values obtained from ELISA testing represented an index of the magnitude of Rs bacteria present, and absolute values were not functionally related (e.g. the difference between 0.08 and 0.09 did not correspond to the difference between 2.5 and 2.7 via a mathematical function). Therefore, to construct metrics for “measuring” levels of BKD, it was prudent to map the values with an indexing system to more robustly represent “distance” between ELISA values. We used the mapping

$$\{(0.000 - 0.199) \rightarrow 1; \quad (0.200 - 0.999) \rightarrow 2; \quad (1.000 - 4.000) \rightarrow 3\}$$

when values across this range occurred. These values, which were used to group results as either low, medium, or high, reflect levels used in previous studies for broodstock segregation. Pascho et al. (1991) categorized infection levels based on the detection of Rs antigen using values of <0.199 as reflecting a low level of infection, 0.2 to 0.999 as a medium level, and values equal to or greater than 1.0 as indicating a high level of infection.

Results

Yearling Chinook Salmon

Gross Necropsy—On gross exam, yearling Chinook with both types of tags appeared to be within normal limits across all sampling sites for eyes, gills, pseudobranchs, and hind gut. Overall, both the AT and PIT-tagged fish recaptured at McNary Dam were scored as more heavily smolted than reference fish sampled at Lower Granite Dam. Fish of both tag treatments recaptured at Bonneville Dam were also scored as being more heavily smolted than reference fish, but less smolted than fish recaptured at McNary Dam. Results from necropsy of reference fish, AT fish, and PIT-tagged fish from all sample sites are displayed in Table 19.

A larger percentage of fish recaptured at McNary Dam were described as having frayed fins than those sampled at Lower Granite Dam. Fish of both tag types recaptured at Bonneville Dam were scored as having the largest percentage of normal fins, with the next largest percentage in reference fish and the lowest percentage in fish recaptured at McNary Dam. Percentages of normal and frayed fins were similar between fish from both tag treatments recaptured at each location.

The percentage of caecal fat reported was higher in reference fish at Lower Granite Dam than in fish of both tag types recaptured at McNary Dam. For both AT and PIT-tagged treatments, recaptures at Bonneville Dam had slightly more fish in the "little" vs. "none" category compared to recaptures at McNary Dam. However, recaptures at Bonneville were still reported to have less caecal fat than reference fish sampled at Lower Granite. At McNary Dam, slightly less caecal fat was reported for AT fish (0.05 in "little" category) than for PIT-tagged fish (0.10 in the ‘little’ and ‘normal’ categories combined). Caecal fat differed by only 0.01 between the two treatments for fish collected at Bonneville Dam.

Table 19. Gross necropsy results for yearling Chinook salmon sampled at Lower Granite Dam (reference) and recaptured at McNary and Bonneville Dam (acoustic and PIT tag treatments). Samples were scored following a Goede index and were evaluated for the metrics listed. Columns show the proportion of treatment fish corresponding to each metric score by location. Standard errors are in parentheses.

	Yearling Chinook Salmon sampled				
	Lower Granite Dam	McNary Dam		Bonneville Dam	
Metric	reference (N = 30)	Acoustic tag (N = 75)	PIT-tag (N = 89)	Acoustic tag (N = 64)	PIT-tag (N = 79)
Smolt_Index					
0-Fully smolted	0.50 (0.09)	0.97 (0.02)	0.98 (0.02)	0.58 (0.06)	0.70 (0.05)
1-Moderately smolted	0.50 (0.09)	0.01 (0.01)	0.02 (0.02)	0.39 (0.02)	0.28 (0.05)
2-Weakly smolted	0.00	0.01 (0.01)	0.00	0.02 (0.02)	0.03 (0.02)
3-No smoltification observed	0.00	0.00	0.00	0.02 (0.02)	0.00
Eyes					
0-Normal	1.0 (0.00)	0.95 (0.03)	0.98 (0.02)	0.98 (0.02)	1.0 (0.00)
1-Diminutive	0.00	0.00	0.00	0.00	0.00
1-Hemorrhagic	0.00	0.05 (0.03)	0.01 (0.01)	0.00	0.00
1-Exopthalmic	0.00	0.00	0.01 (0.01)	0.02 (0.02)	0.00
1-Cataract	0.00	0.00	0.00	0.00	0.00
1Blind or Missing	0.00	0.00	0.00	0.00	0.00
Fins					
0-Normal	0.90 (0.05)	0.68 (0.05)	0.73 (0.05)	0.94 (0.03)	0.95 (0.02)
1-Opaque	0.00	0.03 (0.02)	0.02 (0.02)	0.02 (0.02)	0.00
2-Frayed	0.10 (0.05)	0.30 (0.05)	0.24 (0.05)	0.05 (0.03)	0.05 (0.02)
3-Clubbed or Missing	0.00	0.00	0.00	0.00	0.00
Gills					
0-Normal	1.0 (0.00)	1.0 (0.00)	0.98 (0.02)	1.0 (0.00)	1.0 (0.00)
1-Pale	0.00	0.00	0.02 (0.02)	0.00	0.00
2-Marginate	0.00	0.00	0.00	0.00	0.00
3-Clubbed	0.00	0.00	0.00	0.00	0.00

Table 19. Continued.

	Yearling Chinook Salmon sampled (%)				
	Lower Granite Dam	McNary Dam		Bonneville Dam	
	Reference (N = 30)	Acoustic tag (N = 75)	PIT-tag (N = 89)	Acoustic tag (N = 64)	PIT-tag (N = 79)
Pseudobranchs					
0-Normal	1.0 (0.00)	1.0 (0.00)	1.0 (0.00)	1.0 (0.00)	1.0 (0.00)
1-Swollen	0.00	0.00	0.00	0.00	0.00
2-Lithic	0.00	0.00	0.00	0.00	0.00
3-Swollen and Lithic	0.00	0.00	0.00	0.00	0.00
4-Inflammed	0.00	0.00	0.00	0.00	0.00
Caecal Fat					
0-None	0.43 (0.09)	0.95 (0.03)	0.90 (0.03)	0.81 (0.05)	0.80 (0.05)
1-Little, < 50% of caecum covered	0.37 (0.09)	0.05 (0.03)	0.08 (0.03)	0.14 (0.04)	0.11 (0.04)
2-Normal, 50% of caecum covered	0.20 (0.07)	0.00	0.02 (0.02)	0.05 (0.03)	0.09 (0.03)
3-More than 50% of each caecum covered	0.00	0.00	0.00	0.00	0.00
4-Excessive, pyloric caeca completely covered	0.00	0.00	0.00	0.00	0.00
Mesenteric Fat					
0-No body fat present	0.50 (0.09)	0.79 (0.05)	0.73 (0.05)	0.80 (0.05)	0.76 (0.05)
1-Fat body < diameter of caecum	0.40 (0.09)	0.21 (0.05)	0.26 (0.05	0.20 (0.05)	0.24 (0.05)
2-Fat body = diameter of caecum	0.10 (0.05)	0.00	0.01 (0.01)	0.00	0.00
3-Fat body larger diameter than caecum	0.00	0.00	0.00	0.00	0.00
4-Exceed fat, entire body cavity full of fat	0.00	0.00	0.00	0.00	0.00
Spleen					
0-Red	1.0 (0.00)	0.88 (0.04)	0.90 (0.03)	0.49 (0.06)	0.38 (0.05)
1-Black	0.00	0.02 (0.02)	0.01 (0.01)	0.35 (0.06)	0.57 (0.06)
2-Enlarged	0.00	0.09 (0.03)	0.08 (0.03)	0.05 (0.03)	0.01 (0.01)
3-Granular	0.00	0.00	0.01 (0.01)	0.00	0.00
4-Nodular	0.00	0.00	0.00	0.00	0.00
1,2-Black & Enlarged	0.00	0.00	0.00	0.11 (0.04)	0.04 (0.02)

Table 19. Continued.

	Yearling Chinook Salmon sampled (%)				
	Lower Granite Dam	McNary Dam		Bonneville Dam	
	Reference (N = 30)	Acoustic tag (N = 75)	PIT-tag (N = 89)	Acoustic tag (N = 64)	PIT-tag (N = 79)
Food in Stomach					
Absent	0.87 (0.06)	0.91 (0.03)	0.87 (0.04)	0.56 (0.06)	0.45 (0.06)
Present	0.13 (0.06)	0.09 (0.03)	0.13 (0.04)	0.44 (0.06)	0.55 (0.06)
Hind Gut					
0-No inflammation	1.00 (0.00)	0.97 (0.02)	1.0 (0.00)	1.0 (0.00)	1.0 (0.00)
1-Mild inflammation	0.00	0.01 (0.01)	0.00	0.00	0.00
2-Severe inflammation	0.00	0.01 (0.01)	0.00	0.00	0.00
Liver					
0-Normal; firm reddish brown color	0.93 (0.05)	0.76 (0.05)	0.83 (0.04)	0.63 (0.06)	0.77 (0.05)
1-Slight general discoloration	0.00	0.05 (0.03)	0.00	0.17 (0.05)	0.06 (0.03)
2-Pale	0.07 (0.05)	0.08 (0.03)	0.08 (0.03)	0.20 (0.05)	0.17 (0.04)
3-Fatty liver: coffee-cream color, greasy to touch	0.00	0.08 (0.03)	0.09 (0.03)	0.00	0.00
4-Nodules in liver	0.00	0.00	0.00	0.00	0.00
5-Focal discoloration	0.00	0.04 (0.02)	0.00	0.00	0.00
Gall Bladder					
0-Yellow or straw color; empty or partly full	0.25 (0.08)	0.08 (0.03)	0.20 (0.04)	0.19 (0.05)	0.23 (0.05)
1-Yellow or straw color; full, distended	0.00	0.07 (0.03)	0.07 (0.03)	0.20 (0.05)	0.18 (0.04)
2-light green to "grass" green	0.50 (0.09)	0.57 (0.06)	0.41 (0.05)	0.41 (0.06)	0.53 (0.06)
3-Dark green to dark blue-green	0.25 (0.08)	0.29 (0.05)	0.32 (0.05)	0.20 (0.05)	0.06 (0.03)
Kidney					
0-Normal	1.0 (0.00)	0.97 (0.02)	0.97 (0.02)	0.88 (0.04)	0.87 (0.04)
1-Pale	0.00	0.00	0.02 (0.02)	0.09 (0.04)	0.05 (0.03)
2-Swollen	0.00	0.00	0.00	0.00	0.04 (0.02)
3-Mottled	0.00	0.03 (0.02)	0.01 (0.01)	0.02 (0.02)	0.00
4-Granular	0.00	0.00	0.00	0.02 (0.02)	0.04 (0.02)

Yearling Chinook salmon recaptured at McNary Dam trended towards having less mesenteric fat compared to reference fish sampled at Lower Granite Dam. Mesenteric fat percentages were similar between fish subsampled from McNary and Bonneville Dams. Mesenteric fat content was 0.06 higher for PIT-tagged than AT fish at McNary and 0.04 higher for PIT-tagged than AT fish at Bonneville Dam. All fish sampled at Lower Granite Dam were reported having a normal looking spleen on gross exam. In contrast, 0.09 of the AT and 0.08 of the PIT-tagged fish recaptured at McNary were described as having enlarged spleens, and 0.16 of AT and 0.05 of PIT-tagged fish recaptured at Bonneville were described as having enlarged spleens.

In recaptures from McNary Dam, 0.09 of AT and 0.13 of PIT-tagged fish were observed with food in their stomachs. In recaptures from Bonneville Dam, 0.44 of AT and 0.55 of PIT-tagged fish had food in their stomachs. Gross exam revealed a trend towards higher percentages of liver discoloration in fish sampled from sites further downstream (Bonneville Dam > McNary Dam > Lower Granite Dam). A larger percentage of AT than PIT-tagged fish were observed to have liver abnormalities, with liver abnormality scores 0.08 higher at McNary and 0.14 higher at Bonneville Dam. This was the only metric from gross necropsy that exhibited a statistical difference between treatments at the $\alpha = 0.10$ level ($P = 0.095$ at Bonneville Dam). All fish sampled at Lower Granite Dam had normal appearing kidneys on gross exam. In contrast, both AT and PIT-tagged fish recaptured at McNary Dam had scores of 0.03 for pale or mottled kidneys. In recaptures from Bonneville Dam, study fish from both tag treatments has score of 0.13 for pale, mottled, or granular kidneys.

Histopathologic Evaluation—Table 20 shows results from the comparative histopathology analysis for yearling Chinook salmon by tag treatment (AT and PIT) at McNary and Bonneville Dams. Reference fish were generally healthy, indicating no systematic bias to between-treatment comparisons. Histopathologic evaluations for AT- and PIT-tag treatments were also combined and evaluated by length bin (Table 18).

Results from comparative histopathology analysis for fish recaptured at McNary and Bonneville Dams combined showed significant differences between tag treatments for 15 of 42 metric parameters/condition evaluated. These differences fell into three general categories of nutritional condition, peritoneal inflammation, and incision (AT) or injection site (PIT) healing (Table 20).

Table 20. Results of comparative histopathology analysis by tag treatment (AT vs. PIT) for yearling Chinook salmon subsampled at Bonneville and McNary Dam. ND indicates no difference; light shading indicates a significant difference (α = 0.05); darker shading a significant difference for α = 0.10.

	Tag treatment (Acoustic vs. PIT)			
	McNary Dam		Bonneville Dam	
	Higher prevalence	*P*	Higher prevalence	*P*
Nutritional indicators				
Liver vacuolation	ND		ND	
Pancreatic zymogen	Acoustic	0.094	ND	
Pancreatic atrophy	ND		ND	
Mesenteric adipose	ND		Acoustic	0.014
pyloric caecae mucosal glycogen	ND		Acoustic	0.090
Small intestinal digesta presence	ND		ND	
Lower intestinal mucosal glycogen	ND		PIT	0.036
Lower intestinal digesta presence	PIT	0.021	ND	
Liver hydropic vacuolation*	Acoustic	0.006	ND	
Inflammatory indicators				
Pancreatic inflammation	ND		PIT	0.026
Small intestinal inflammation	ND		ND	
Lower intestinal inflammation	ND		ND	
Heart epi/myocarditis	ND		ND	
Spleen congestion	Acoustic	0.027	ND	
Spleen lymphoid depletion	ND		ND	
Spleen fibrosis	ND		ND	
Mesenteric chronic inflammation	ND		ND	
Mesenteric chronic inflammation severity	ND		ND	
Peritonitis, chronic	Acoustic	0.042	Acoustic	0.003
Degenerative indicators				
Liver coagulative necrosis	ND		ND	
Liver eosinophilic hypertrophy	ND		ND	
Kidney tubule epithelial necrosis	ND		ND	
Infectious indicators/agents				
Liver lymphocytic infiltrates	ND		ND	
Liver BKD lesions	ND		ND	
Liver Ceratomyxa lesions	ND		ND	
Small intestinal digenetic trematodes	ND		ND	
Small intestinal Ceratomyxa	ND		ND	
Lower intestinal digenetic trematodes	ND		ND	
Kidney BKD lesions	ND		ND	
Kidney tubule Myxosporea	ND		ND	

Table 20. Continued.

	Tag treatment (Acoustic vs. PIT)			
	McNary Dam		Bonneville Dam	
	Higher prevalence	*P*	Higher prevalence	*P*
Incision/injection site healing				
Incision closure	ND		PIT	0.011
Skin stratum compactum reknit	PIT	0.002	PIT	0.054
Incision chronic inflammation	ND		ND	
Incision chronic inflammation severity	ND		Acoustic	0.001
Dermal muscular necrosis	ND		ND	
Dermal hemorrhage/fibrin	ND		ND	
Incision, poor apposition	Acoustic	0.000	Acoustic	0.000
Incision, adhesions	Acoustic	0.008	ND	
Internal organ evulsion via incision and presence of Saprolegnia	ND		ND	
Miscellaneous indicators				
Kidney tubule HYDVAC	ND		ND	
Small intestinal mucosal glycogen	ND		PIT	0.004
Spleen macrophage aggregates	ND		ND	

* Can indicate inadequate diet in some mammals; unknown relation to diet in salmonids

Of the histological indicators of nutritional status (e.g. liver vacuolation, pancreatic zymogen, pancreatic atrophy, mesenteric adipose, lower intestinal mucosal glycogen, and intestinal digesta presence), there was no clear trend in the direction of differences between treatments. At McNary Dam, the prevalence of pancreatic zymogen (a digestive enzyme) was significantly higher in AT fish at the 0.094 level, while the presence of digesta in the lower intestine was significantly higher in PIT-tagged fish ($P = 0.021$). Hydropic vacuolation in the liver was significantly higher in AT fish ($P = 0.006$). Although primarily thought of as an indicator of toxin exposure in fish, this histologic change has been observed in mammalian tissue following a dietary stress.

At Bonneville Dam, lower intestinal mucosal glycogen stores were significantly higher in PIT-tagged than AT fish ($P = 0.036$). Pyloric caecae mucosal glycogen stores were higher in AT fish, and the difference was significant at the 0.090 level. At Bonneville Dam, mesenteric adipose was significantly higher in AT fish ($P = 0.014$).

Comparative histopathology between tag treatments for individual recapture sites (McNary and Bonneville Dam) showed consistent trends with respect to inflammation within the peritoneal cavity and incision closure. Chronic peritonitis was significantly higher in AT than PIT-tagged fish at McNary (P = 0.042) and Bonneville Dam (P = 0.003), and incision adhesions were observed more often in AT than PIT-tagged fish at McNary Dam (P = 0.008). Similar to incision adhesions, chronic peritonitis was evaluated internally at the site of the incision, and largely reflected inflammation and adhesions at this location. Although an infectious cause for the observed inflammation cannot be ruled out, there were no obvious signs of infection, such as large amounts of bacteria, in any yearling Chinook samples evaluated.

Poor apposition of the incision was also more common in AT than PIT-tagged fish at both Bonneville (P = 0.000) and McNary Dam (P = 0.000). Uneven closure of the body wall surfaces to either side of the incision or injection site can increase the likelihood that pathogens will enter the body cavity. In addition, reknitting of the stratum compactum was significantly more prevalent in PIT than AT fish at McNary Dam (P = 0.002) and at the 0.054 level at Bonneville Dam, indicating that PIT-tag injection sites were healing earlier than the surgical incisions. At Bonneville Dam, incision closure was rated significantly higher in PIT than AT fish (P = 0.011), while incision chronic inflammation severity was significantly higher in AT than PIT-tagged fish (P = 0.001). Splenic congestion (an indicator of stress) was significantly higher in AT than PIT-tagged fish at McNary Dam (P = 0.027). Additional metrics that differed significantly between treatments included pancreatic inflammation and small intestinal mucosal glycogen, which were both higher in PIT-tagged than AT fish at Bonneville Dam (P = 0.026 and P = 0.004 respectively).

For yearling Chinook salmon with both AT and PIT tag types combined, comparisons of histologic indicators by length bin showed two significant trends (α = 0.05; Table 21). First, at McNary Dam, mesenteric adipose was greater in the 14-16 cm bin than the 13-cm bin and greater in the 13 than the 11-12 cm bin (P<0.050). Second, at Bonneville Dam, poor incision apposition was observed more frequently in smaller fish (11-12 > 13, 14, and 15-16 cm; P = 0.006). In addition, liver eosinophilic hypertrophy in fish recaptured from McNary Dam was greater in larger fish 14, 15-16 > 11-12 cm at the 0.074 level; however, this metric was observed in only 2 fish. At McNary Dam, a higher prevalence of liver lymphocytic infiltrates was seen in fish from in the 13-cm bin than in those from the 11-12, 14, and 15-16 cm bins (P = 0.002). Also at McNary Dam, small intestinal mucosal glycogen in was greater in fish from the 14-cm than those from the 11-12, 13, and 15-16 cm bins (P = 0.036).

Table 21. Results of comparative histopathology analysis for yearling Chinook salmon by length bin (11-12, 13, 14, or 15-16 cm) class recaptured at Bonneville and McNary Dam (AT and PIT combined). ND indicates no difference, light shading indicates a significant difference for α = 0.05; dark shading for difference at α = 0.10

	Length bin (cm)			
	McNary Dam		Bonneville Dam	
	Higher prevalence	*P*	Higher prevalence	*P*
Nutritional indicators				
Liver vacuolation	ND		ND	
Pancreatic zymogen	ND		ND	
Pancreatic atrophy	ND		ND	
Mesenteric adipose	11-12 < 13 <14	0.049, 0.003	ND	
pyloric caecae mucosal glycogen	ND		ND	
Small intestinal digesta presence	14 < 11-12, 13, 15-16	0.036	ND	
Lower intestinal mucosal glycogen	ND		ND	
Lower intestinal digesta presence	ND		ND	
Liver hydropic vacuolation [a]	ND		ND	
Inflammatory indicators				
Pancreatic inflammation	ND		ND	
Small intestinal inflammation	ND		ND	
Lower intestinal inflammation	ND		ND	
Heart epi/myocarditis	ND		ND	
Spleen congestion	ND		ND	
Spleen lymphoid depletion	ND		ND	
Spleen fibrosis	ND		ND	
Mesenteric chronic inflammation	ND		ND	
Mesenteric chronic inflammation severity	ND		ND	
Peritonitis, chronic	ND		ND	
Degenerative indicators				
Liver coagulative necrosis	ND		ND	
Liver eosinophilic hypertrophy[b]	14,15-16 > 11-12	0.074	ND	
Kidney tubule epithelial necrosis	ND		ND	
Infectious indicators/agents				
Liver lymphocytic infiltrates	13 > 11-12, 14, 15-16	0.002	ND	
Liver BKD lesions	ND		ND	
Liver Ceratomyxa lesions	ND		ND	
Small intestinal digenetic trematodes	ND		ND	
Small intestinal Ceratomyxa	ND		ND	
Lower intestinal digenetic trematodes	ND		ND	
Kidney BKD lesions	ND		ND	
Kidney tubule Myxosporea	ND		ND	

Table 21. Continued.

	Length bin (cm)			
	McNary Dam		Bonneville Dam	
	Higher prevalence	*P*	Higher prevalence	*P*
Incision/injection site healing				
Incision closure	ND		ND	
Skin stratum compactum reknit	ND		ND	
Incision chronic inflammation	ND		ND	
Incision chronic inflammation severity	ND		ND	
Dermal muscular necrosis	ND		ND	
Dermal hemorrhage/fibrin	ND		ND	
Incision, poor apposition	ND		11-12>13, 14, 15-16	0.006
Incision, adhesions	ND		ND	
Internal organ evulsion via incision	ND		ND	
and presence of Saprolegnia	ND		ND	
Miscellaneous indicators				
Kidney tubule HYDVAC	ND		ND	
Small intestinal mucosal glycogen	ND		ND	
Spleen macrophage aggregates	ND		ND	

a Can indicate inadequate diet in some mammals; unknown relation to diet in salmonids

b Two affected fish

Prevalence of *Renibacterium salmoninarum*—Estimated Rs antigen levels in hatchery Chinook salmon, as measured by ELISA, ranged from 0.070 to 0.131 for fish sampled at Lower Granite Dam prior to tagging. ELISA values ranged from 0.070 to 0.133 for fish recaptured at McNary Dam, and from 0.068 to 0.298 (with 2 others at 0.463 and 1.613) for fish recaptured at Bonneville Dam. Since ELISA values for all but a few fish were considered low, no statistical analyses were conducted to evaluate differences between sites or among treatment groups.

Subyearling Chinook Salmon

Gross Necropsy—At Bonneville Dam, 80 subyearling Chinook salmon were recaptured via SbyC and immediately euthanized. Results from gross necropsy of these fish and reference fish sampled at Lower Granite Dam are displayed in Table 22 (no tagged fish were sampled at McNary Dam, as the SbyC system was not operating during this period of the study). Samples were scored numerically following a Goede index (Geode and Barton 1990). A description of the numeric scale used to evaluate the metrics presented is included in Table 22.

On gross exam, the majority of fish showed no departure from normal at both sampling sites and for both tag treatments for gills, pseudobranchs, eyes, and hind gut metrics. Overall, subyearling Chinook salmon recaptured at Bonneville Dam (both AT and PIT-tagged) were described as being more heavily smolted than reference fish. Proportions of fish with normal fins were high, ranging from 1.00 for reference fish sampled at Lower Granite Dam and AT fish recaptured at Bonneville to 0.88 for PIT-tagged fish recaptured at Bonneville Dam. For PIT-tagged fish recaptured at Bonneville Dam, 0.12 were described as having opaque or frayed fins.

The percent of caecal fat reported in study fish decreased from Lower Granite Dam to Bonneville Dam, and in general, there was less caecal fat observed in AT (89% rated as having none) than in PIT-tagged (76% rated as having none) fish recaptured at Bonneville. The same trend held for percent mesenteric fat (89 and 82% of AT and PIT-tagged fish respectively rated as having none). Of the reference fish sampled at Lower Granite Dam, 3% were described as having enlarged spleens compared to respective proportions of 0 and 11% for AT and PIT-tagged fish recaptured at Bonneville Dam.

At Bonneville Dam, proportions of fish with food in the stomach were 0.57 for AT and 0.52 for PIT-tagged treatments. The percentage of fish with liver discoloration was higher in fish recaptured at Bonneville Dam compared to reference fish. At Bonneville Dam, AT fish showed a higher percentage of liver discoloration than PIT-tagged fish (AT-PIT = 0.09). From gross exam, nearly all non-tagged reference fish (0.99) sampled at Lower Granite Dam had normal looking kidneys. At Bonneville Dam, proportions of 0.33 AT fish and 0.14 PIT-tagged fish were reported to have either pale or swollen kidneys. None of the gross necropsy comparisons between treatments were statistically significant. However, the sample size was very small for AT fish (N = 9), so these data cannot support any specific inferences.

Table 22. Gross necropsy results for subyearling Chinook salmon sampled at Lower Granite Dam (reference fish) and recaptured at Bonneville Dam (AT and PIT-tagged fish). Samples were scored following a Goede index and were evaluated for the metrics listed. Columns show the percentage of treatment fish corresponding to each metric score by location. Standard errors are represented in parentheses.

	Fish affected		
	Lower Granite	Bonneville	
	reference (N = 79)	AT (N = 9)	PIT (N = 71)
Smolt_Index			
0-Fully smolted	0.52 (0.06)	1.00 (0.00)	0.94 (0.03)
1-Moderately smolted	0.44 (0.06)	0.00	0.06 (0.03)
2-Weakly smolted	0.05 (0.02)	0.00	0.00
3-No smoltification observed	0.00	0.00	0.00
Eyes			
0-Normal	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
1-Diminutive	0.00	0.00	0.00
1-Hemorrhagic	0.00	0.00	0.00
1-Exopthalmic	0.00	0.00	0.00
1-Cataract	0.00	0.00	0.00
1Blind or Missing	0.00	0.00	0.00
Fins			
0-Normal	1.00 (0.00)	1.00 (0.00)	0.88 (0.04)
1-Opaque	0.00	0.00	0.10 (0.04)
2-Frayed	0.00	0.00	0.02 (0.02)
3-Clubbed or Missing	0.00	0.00	0.00
Gills			
0-Normal	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
1-Pale	0.00	0.00	0.00
2-Marginate	0.00	0.00	0.00
3-Clubbed	0.00	0.00	0.00
Pseudobranchs			
0-Normal	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
1-Swollen	0.00	0.00	0.00
2-Lithic	0.00	0.00	0.00
3-Swollen and Lithic	0.00	0.00	0.00
4-Inflammed	0.00	0.00	0.00
Caecal Fat			
0-None	0.63 (0.05)	0.89 (0.11)	0.76 (0.05)
1-Little, > 50% of caecum covered	0.28 (0.05)	0.11 (0.10)	0.24 (0.05)
2-Normal, 50% of caecum covered	0.09 (0.03)	0.00	0.00
3-More than 50% of each caecum covered	0.00	0.00	0.00
4-Excessive, pyloric caeca completely covered by large amount of fat	0.00	0.00	0.00

Table 22. Continued.

	Fish affected (%)		
	Lower Granite	Bonneville	
	reference	AT	PIT
	(N = 79)	(N = 9)	(N = 71)*
Mesenteric Fat			
0-No body fat present	0.65 (0.05)	0.89 (0.10)	0.82 (0.05)
1-Fat body less than diameter of caecum	0.25 (0.05)	0.11 (0.10)	0.18 (0.05)
2-Fat body equal in diameter of caecum	0.10 (0.03)	0.00	0.00
3-Fat body larger diameter than caecum	0.00	0.00	0.00
4-Exceed fat, entire body cavity full of fat	0.00	0.00	0.00
Spleen			
0-Red	0.97 (0.02)	0.22 (0.14)	0.32 (0.06)*
1-Black	0.00	0.78 (0.14)	0.56 (0.06)
2-Enlarged	0.03 (0.02)	0.00	0.01 (0.01)
3-Granular	0.00	0.00	0.00
4-Nodular	0.00	0.00	0.00
1,2-Black & Enlarged	0.00	0.00	0.10 (0.04)
Food in Stomach			
Absent	1.00 (0.00)	0.43 (0.16)	0.48 (0.06)*
Present	0.00	0.57 (0.17)	0.52 (0.06)
Hind Gut			
0-No inflammation	1.00 (0.00)	1.00 (0.00)	0.99 (0.01)
1-Mild inflammation	0.00	0.00	0.00
2-Severe inflammation	0.00	0.00	0.01 (0.01)
Liver			
0-Normal; firm reddish brown color	0.90 (0.03)	0.56 (0.17)	0.65 (0.06)
1-Slight general discoloration	0.04 (0.02)	0.33 (0.16)	0.32 (0.06)
2-Pale	0.06 (0.03)	0.11 (0.10)	0.03 (0.02)
3-Fatty liver: coffee-cream color, greasy to touch	0.00	0.00	0.00
4-Nodules in liver	0.00	0.00	0.00
5-Focal discoloration	0.00	0.00	0.00
Gall Bladder			
0-Yellow or straw color; bladder empty or partially full	0.11 (0.04)	0.44 (0.17)	0.42 (0.06)
1-Yellow or straw color; bladder full, distended	0.00	0.22 (0.14)	0.25 (0.05)
2-light green to "grass" green	0.86 (0.04)	0.33 (0.16)	0.30 (0.05)
3-Dark green to dark blue-green	0.03 (0.02)	0.00	0.03 (0.02)
Kidney			
0-Normal	0.99 (0.01)	0.67 (0.16)	0.86 (0.04)
1-Pale	0.01 (0.01)	0.33 (0.16)	0.13 (0.04)
2-Swollen	0.00	0.00	0.01 (0.01)
3-Mottled	0.00	0.00	0.00
4-Granular	0.00	0.00	0.00

* N = 69 for PIT spleen and Food in stomach at Bonneville

Histologic Evaluation—Table 23 shows comparative histopathology analysis by treatment (AT vs. PIT-tag) for subyearling Chinook recaptured at Bonneville Dam, along with analysis by length-class for both tag types combined. Reference fish were generally healthy, indicating no systematic bias to between-treatment comparisons. No AT pilot fish (85-94 mm) were recaptured at the dams, so none were available for histological analysis.

A total of 43 parameters or conditions were evaluated by histological exam for subyearling Chinook salmon (parameters and scoring indices are detailed in Appendix E). Results from comparative histopathology between tag treatments recaptured at Bonneville Dam (Table 23) showed significant differences for 5 of the 43 parameters/conditions evaluated at $\alpha = 0.05$, and for one additional parameter evaluated at $\alpha = 0.10$. Similar to the yearling fish, the majority of these differences fell into general categories describing peritoneal inflammation and healing at the incision or injection site.

At Bonneville Dam, chronic peritonitis was rated significantly higher in AT than PIT-tagged fish ($P = 0.007$); mesenteric chronic inflammation severity was also higher in AT fish and the difference was significant at the 0.075 level. The severity of chronic inflammation at the incision site was significantly higher in AT fish ($P = 0.011$) as was the presence of dermal hemorrhage/fibrin at the site of the incision ($P = 0.009$). Reknitting of the skin stratum compactum layer (healing) was significantly higher in PIT-tagged fish ($P = 0.001$). Reserves of glycogen in the small intestine were also significantly higher in PIT-tagged fish ($P = 0.020$), though this index is not a particularly strong indicator of nutritional status.

For fish from both tag treatments recaptured at Bonneville Dam, analysis by length bin revealed a pronounced clear pattern for the presence/absence of liver lymphocytic infiltrates: Smaller fish had these cells more frequently than larger fish (9-10, 11>12-13 cm), and the difference was significant at the 0.090 level. Mesenteric adipose was significantly greater in 12-13 cm fish than in 9-11 cm fish ($P = 0.033$). Myxosporea in the kidney tubules were observed more often in fish belonging to the 9-10 cm than 11 and 12-13 cm bins, and the difference was significant at the 0.092 level. Incision adhesions were observed more often in larger fish (12-13 > 9-10, 11 cm), and the difference was significant at the 0.057 level.

Table 23. Results of comparative histopathology analysis of subyearling Chinook salmon by tag treatment (Acoustic vs. PIT) and length bin for (9-10, 11, and 12-13 cm) recaptured at Bonneville Dam. ND indicates no difference; light shading indicates a significant difference; dark shading indicates a difference with α at the 0.10 level.

	Tag treatment		Length bin (cm)	
	Higher prevalence	*P*	Higher prevalence	*P*
Nutritional indicators				
Liver vacuolation	ND		ND	
Pancreatic zymogen	ND		ND	
Pancreatic atrophy **a**	ND		ND	
Mesenteric adipose	ND		9-11<12-13	0.033
pyloric caecae mucosal glycogen	ND		ND	
Small intestinal digesta presence	ND		ND	
Lower intestinal mucosal glycogen	ND		ND	
Lower intestinal digesta presence	ND		ND	
Liver hydropic vacuolation **b,c**	ND		ND	
Inflammatory indicators				
Pancreatic inflammation	ND		ND	
Small intestinal inflammation	ND		ND	
Lower intestinal inflammation	ND		ND	
Heart epi/myocarditis **b**	ND		ND	
Spleen congestion	ND		ND	
Spleen lymphoid depletion **b**	ND		ND	
Spleen fibrosis **b**	ND		ND	
Mesenteric chronic inflammation	ND		ND	
Mesenteric chronic inflammation severity	Acoustic	0.075	ND	
Peritonitis, chronic	Acoustic	0.007	ND	
Degenerative indicators				
Liver coagulative necrosis **b**	ND		ND	
Liver eosinophilic hypertrophy **d**	ND		ND	
Kidney tubule epithelial necrosis **b**	ND		ND	
Infectious indicators/agents				
Liver lymphocytic infiltrates	ND		9-10, 11>12-13	0.090
Liver BKD lesions **b**	ND		ND	
Liver Ceratomyxa lesions **d**	ND		ND	
Small intestinal digenetic trematodes	ND		ND	
Small intestinal Ceratomyxa	ND		ND	
Lower intestinal digenetic trematodes	ND		ND	
Kidney BKD lesions **b**	ND		ND	
Head kidney BKD[e] lesions **a**	ND		ND	
Kidney tubule Myxosporea	ND		9-10>11,12-13	0.092

Table 23. Continued.

	Tag treatment		Length bin	
	Higher prevalence	*P*	Higher prevalence	*P*
Incision/injection site healing				
Incision closure	ND		ND	
Skin stratum compactum reknit	PIT	0.001	ND	
Incision chronic inflammation	ND		ND	
Incision chronic inflammation severity **e**	Acoustic	0.011	ND	
Dermal muscular necrosis	ND		ND	
Dermal hemorrhage/fibrin	Acoustic	0.009	ND	
Incision, poor apposition **b**	ND		ND	
Incision, adhesions	ND		9-10, 11 <12-13	0.057
Internal organ evulsion via incision and presence of Saprolegnia **b**	ND		ND	
Miscellaneous indicators				
Kidney tubule HYDVAC **b**	ND		ND	
Small intestinal mucosal glycogen	PIT	0.020	ND	
Spleen macrophage aggregates	ND		ND	

a Two affected fish
b No affected fish
c May indicate inadequate diet in some mammals; unknown relation to diet in salmonids
d One affected fish
e Trend of greater inflammation in larger fish

Prevalence of *Renibacterium salmoninarum*—Baseline Rs antigen levels measured by ELISA from subyearling Chinook reference fish sampled at Lower Granite Dam ranged from 0.070 to 0.213. Rs antigen levels were estimated for subyearling Chinook treatment fish of both tag treatments combined (AT and PIT) that were recaptured at Bonneville Dam. For the combined tag treatments, Rs antigen levels ranged from 0.078 to 0.442 overall and exceeded 0.299 in only two of these fish. Since ELISA values for all but a few fish were considered low, no statistical analysis was conducted to evaluate differences between detection sites or among treatment groups.

Discussion

With few exceptions, two overall trends seemed to stand out from the gross necropsy and histological examinations of both yearling and subyearling Chinook salmon. First, there was greater evidence of inflammatory lesions in treatment fish recaptured at downstream sites (McNary and Bonneville Dams) than in reference fish. Second, and to a lesser extent, the overall condition of both AT and PIT-tagged fish collected at downstream locations (McNary and Bonneville Dams) was inferior to that of reference fish.

For both yearling and subyearling Chinook, inflammatory lesions were more prevalent in AT than PIT-tagged fish, and wound healing had progressed further in PIT than AT fish. Also, AT fish may have experienced loss of condition to a greater extent than PIT-tagged fish (yearling and subyearling fish). However, the nutritional differences inferred between treatments were based largely on trends in the gross necropsy results rather than on statistical differences, so these inferences should be read with caution. Inferences regarding subyearling fish cannot be well supported due to the small sample sizes for this group overall, and the particularly small sizes for AT fish (N = 9).

Overall, the yearling Chinook salmon sampled at Lower Granite Dam as reference fish appeared healthy, as few abnormalities were noted on gross necropsy and histological exam. Further, ELISA testing for the Rs antigen revealed low levels in all baseline fish. External lesions were also rare in fish recaptured downstream; however, our sampling protocol, which targeted the first 10 fish encountered from each treatment/release group, may have biased the subsamples toward more robust fish compared to the group at large.

In the yearling Chinook salmon, internal indicators of inflammation and/or infection (discoloration in the liver and kidneys) and stress (splenic enlargement) were grossly visible in fish from both treatment groups recaptured downstream. Furthermore, inflammatory lesions in the kidney and liver were more prevalent in fish recaptured at Bonneville than McNary Dam, suggesting that as they moved downriver, affected fish from both tag treatments may have been responding to the implants or to previously latent or newly acquired pathogens and parasites. Notably, liver abnormalities were more prevalent in AT fish recaptured at both downstream sites, and splenic enlargement was more prevalent in AT than in PIT-tagged fish recaptured at Bonneville Dam.

Results of comparative histology analyses supported observations from gross necropsy that inflammatory lesions were more prevalent in AT than PIT-tagged fish. Comparisons by tag treatment showed that the incidence of chronic peritonitis was significantly higher in AT than in PIT-tagged fish at both McNary and Bonneville Dams. Peritonitis was evaluated locally, at the site of the incision, and may have been a primary reaction to the tag. Although copious bacteria were not observed in the tissue sections examined, the tissue reactivity may have also been elicited by a secondary infection introduced during the surgical procedure or post-operatively through the incision site.

Comparative histology results suggested that PIT-tag injection sites had healed cleaner and faster than the surgery incisions, and incision apposition was rated as poor significantly more often for AT fish than for PIT-tagged fish at both recapture locations. Poor or uneven apposition of the two sides of the incision would predispose fish to secondary infections by exposing the underlying dermal tissue to river water, which can be teaming with bacteria and fungi. The AT and/or PIT tags could have introduced bacteria directly into the peritoneal cavity as well. Both sterile and infectious reactions have been observed by others in surgically tagged fish (Brown et al. 2007a; Bunnell and Isely 1999; Chisholm and Hubert 1985; Knights and Lasee 1996; Liedtke et al. 2007; Marty and Summerfelt 1986, 1990; Walsh et al. 2000).

Although inflammation appeared to show a consistent pattern of increase from release to each successive downstream detection site for both tag treatment groups, the nutritional indices did not show such a concise pattern. Compared to reference fish collected at Lower Granite Dam, the condition of yearling Chinook from both tag treatments at both recapture sites appeared to deteriorate as fish migrated downstream. This may indicate that yearling Chinook salmon were not receiving sufficient nutrition to maintain their metabolic needs during migration. Fish from both tag treatments at both recapture sites had lower nutritional reserves than reference fish. However, fish sampled at Bonneville were observed to have larger amounts of caecal fat grossly than those recaptured at McNary, and mesenteric fat did not appear to vary by more than a few percentage points between the two sites. In addition, a larger percentage of fish recaptured at Bonneville than McNary Dam were rated as having food in the stomach.

The different nutritional condition between fish collected at McNary and Bonneville Dams may indicate that river conditions were more favorable in the Columbia than the Snake River (e.g. more food was available) or that hatchery fish had transitioned to a more natural diet. The difference may also have been an artifact of sampling. Fish that failed to forage successfully may have dropped out of the population between McNary and Bonnville Dam, thus high grading our potential sample population at the lower river site.

In addition to the overall trend that recaptured study fish were less fit than reference fish, the gross necropsy examinations suggested that AT fish were either taking in less food or utilizing nutritional reserves to a greater extent than PIT-tagged fish, possibly due to the extra weight or bulk of the AT tag or because they appeared to be devoting more energy towards inflammatory type responses. Caecal fat was slightly higher in PIT-tagged fish recaptured at McNary Dam, and mesenteric fat was higher in PIT-tagged fish recaptured at both downstream dams. In addition, a higher percentage of PIT than AT fish were observed with food in their stomachs at both dams. However, these comparisons indicated no significant differences, and in general, yearling Chinook are not thought to forage extensively during the downstream migration (Connor et al. 2004).

Furthermore, nutritional observations from gross necropsy were not fully consistent with histological metrics evaluated at either McNary or Bonneville Dam. While differences in nutritional indicators between treatments were significant, they were inconsistent in direction between recapture locations. Findings between the gross necropsy and histological evaluation appeared somewhat inconsistent with respect to mesenteric adipose. However, this discrepancy may have been due to the large difference in scale between these comparisons. Histological assessment was conducted on several small pieces of tissue (primarily pyloric caecae and mesenteric tissues surrounding other organs collected) while gross examination was based on a whole animal assessment.

In the combined dataset, histological comparisons among size classes for the amount of mesenteric adipose tissue present at McNary Dam indicated that larger fish overall may have been more fit than smaller fish when they reached the downstream recapture sites. Comparisons by size bin also suggested that incision closure was less complete for the smaller fish at tagging by the time they had reached Bonneville Dam.

Subyearling Chinook sampled for baseline data at Lower Granite Dam appeared to be healthy. Aside from a few livers that were grossly discolored, few other abnormalities were noted internally or externally on gross necropsy and histological exam. Testing for Rs antigen revealed low levels in all but a few of the subyearling baseline fish. Grossly visible external lesions were also rare in fish recaptured downstream; however, we were only able to obtain 9% of our target sample for the AT fish. This was presumably due to high mortality prior to fish reaching Bonneville Dam.

Internally, indicators of inflammation and/or infection (discoloration in the liver and kidneys) were grossly visible in recaptured fish from both treatment groups. As for yearling fish, this suggested that as they migrated downstream, subyearlings may have been responding to implants or to previously latent or newly acquired pathogens and parasites. Also similar to yearling fish, signs of obvious infection such as large amounts of bacteria or fungi were not observed in subyearling tissues sampled for histology.

Evidence of inflammation was greater in AT than PIT-tagged fish based on both gross necropsy and histological exam. Necropsy showed a higher percentage of AT than PIT-tagged fish with generalized liver and kidney discoloration, and histological exam showed that both chronic peritonitis and the severity of chronic inflammation at the incision were significantly more prevalent in AT than PIT-tagged fish. Also similar to the yearling fish, comparative histological analyses indicated that injection wounds in PIT-tagged fish were healing faster and cleaner than incisions in AT fish (stratum compactum reknitting (PIT>AT) and dermal hemorrhage/fibrin (AT>PIT). Size class comparisons revealed more evidence of inflammation in smaller fish, as indicated by the greater presence of liver lymphocytic infiltrates in smaller than in larger fish. This metric is commonly used as an indicator for the presence of BKD.

Similar to the yearling comparisons, gross necropsy of the subyearlings indicated that these fish were utilizing energy rather than building nutritional reserves as they migrated downstream, and that this phenomenon was more pronounced in AT than PIT-tagged fish. Gross necropsy indicated that caecal and mesenteric adipose tissues were present in greater amounts in PIT than AT fish.

These observations and results indicate that subyearling AT fish likely experienced higher metabolic demands than PIT-tagged fish as they migrated inriver. This increased demand may have been due to the added bulk and weight of the acoustic tags or to the demands of mounting an inflammatory reaction. Overall, the AT fish appeared to be taxed with more inflammatory type reactions than PIT-tagged fish (e.g. histological evidence of chronic inflammation in the mesentery, chronic peritonitis, chronic inflammation at the incision, and gross evidence of inflammation in the kidneys and livers). These reactions could have been elicited by the presence of the acoustic tag or by infection sustained during or post-surgery as fish attempted to heal.

Finally, although there was no indication from gross or histological exam that AT fish had stopped eating to a greater degree than PIT-tagged fish, it is possible that the acoustic implants acted as mechanical appetite suppressants. Similar to the yearling comparisons, mesenteric fat was significantly higher at Bonneville Dam for larger subyearling fish (AT and PIT combined) at release. Unlike the yearling Chinook, subyearlings are thought to feed and grow significantly during the juvenile migration (Connor et al. 2004). Comparative analyses of Rs antigen levels did not indicate that AT fish were more vulnerable to BKD than PIT-tagged fish.

EXTENDED HOLDING OF ACOUSTIC- AND PIT-TAGGED JUVENILE SALMON

Executive Summary

Yearling Chinook Salmon. For extended holding and observation of yearling Chinook salmon, 40 reference fish and 40 fish from each tag treatment (AT and PIT) were subsampled on each of 10 release days during collection and tagging for migration behavior and survival releases (1,200 total). Reference fish were collected, held, and anesthetized as AT fish, but were not tagged. After tagging, reference and treatment fish were transported directly from Lower Granite Dam to the Bonneville Dam Second Powerhouse Juvenile Monitoring Facility. These fish were held in laboratory tanks for a total of 90 d to observe tag loss, tissue response to tagging, and long-term survival. Fish were tested for the antigen to *Renibacterium salmoninarum* (Rs) using an ELISA. We also collected CWTs from hatchery marked fish in each sample group to examine survival trends within individual hatchery release groups.

For fish held for long-term observation, mean survival among the three groups was significantly different after 14 d: survival of AT fish (0.85) was significantly lower than that of PIT-tagged (0.92) and reference fish (0.93; Fisher's LSD; $P = 0.027$). This difference persisted and continued to be significant ($P = 0.012$) at 28 d. By 90 d holding, although the trend among treatment groups persisted, differences among group means were no longer significant. Among fish that survived 90 d, mean growth was 3.6 mm greater for PIT-tagged than AT fish ($P = 0.068$).

No yearling Chinook that survived to the end of the 90-d holding period expelled or dropped an acoustic tag. The AT fish that survived to termination dropped PIT tags at a rate of 2.0% (n = 5 tags, 1 tag lost for releases 1, 3, 4, 6, and 7) while PIT-tagged fish that survived to termination dropped PIT tags at a rate of 0.3% (n = 1, release 1). The difference in PIT-tag loss between treatment groups was significant at the 0.064 level. Both acoustic and PIT-tag losses were determined post-mortem at the time of necropsy. Due to the small number of tags recovered from holding tanks, it was not possible to determine the timing of tag loss.

In fish that died before termination of the study, there were no significant differences in Rs antigen levels among treatment groups ($P = 0.774$). There were also no significant differences in Rs levels among treatment groups in fish that survived through termination of the study ($P = 0.993$).

Evidence from CWTs collected from laboratory fish indicated that no single hatchery group contributed fish to our study that were obviously compromised in numbers sufficient to bias the results.

Subyearling Chinook Salmon. For long-term holding evaluations, 40 fish from each of four study groups (reference, AT, AT pilot, and PIT-tag) were subsampled from 9 of the 27 release groups of subyearling Chinook salmon collected at Lower Granite Dam. Reference fish were collected, anesthetized, and held as AT fish, but were not tagged. After tagging, all fish were transported directly to the juvenile monitoring facility at Bonneville Dam. These fish were taken throughout the summer study and held at Bonneville in laboratory tanks for 90 d to observe tag loss, tissue response to tagging, long-term survival, and prevalence of Rs antigen. We also collected CWTs from hatchery fish to evaluate the potential influence of hatchery fish on survival, as described above for yearling Chinook salmon.

In the laboratory, mean survival among treatment groups at 14 d holding was significantly different, with survival significantly lower for AT fish (0.53) than for PIT-tagged (0.94) or reference fish (0.88; Fisher's LSD, $P = 0.010$). A comparison of mean survival among groups also revealed a significant difference at 14 d ($P = 0.000$), with the AT pilot group showing considerably lower survival (0.18) than the other three groups. These differences persisted and continued to be significant through the holding period. Among fish that survived to 90 d, mean growth was 4.5 mm higher for PIT-tagged than for AT fish ($P = 0.061$) and the mean difference in weight gain was 3.4 g ($P = 0.246$).

For subyearlings that survived to the end of the 90-d holding period, 7.6% of AT fish passively dropped or expelled acoustic tags, while none of the AT pilot fish surviving to termination dropped or expelled tags. Fish losing AT tags were from release groups 11 (4 tags), 12 (1 tag), 16 (1 tag), 17 (1 tag), and 18 (2 tags). The AT fish lost PIT tags at a rate of 3.4% (one tag each for releases 11, 15, 16, and 17), while no PIT tags were lost from the AT pilot or PIT-tagged fish groups. The difference in PIT-tag loss between AT and PIT-tagged fish was significant ($P = 0.002$). Neither acoustic- nor PIT-tag loss was compared using fish from the AT pilot group due to small numbers of survivors in that group. Similar to the yearling group, tag loss was determined post-mortem at the time of necropsy. Due to the small number of tags recovered from the holding tanks, it was not possible to determine the timing of tag loss.

Rs antigen values as measured by an ELISA for subyearling laboratory fish that died before termination of the study ranged from 0.055 to 2.264. There were no significant differences in Rs antigen levels among study groups ($P = 0.584$). Rs antigen levels for fish that survived until experiment termination at 90 d ranged from 0.040 to 0.240. Because nearly all fish held to termination had low levels of Rs antigen, significance testing to evaluate differences among groups was not conducted.

Evidence from coded-wire tags collected from laboratory fish indicated that no single hatchery group contributed fish to our study that were obviously compromised in numbers sufficient to cause bias of any study results.

Introduction

During field evaluations of migration behavior and survival for yearling and subyearling Chinook salmon, we held subsamples of each release group in laboratory tanks for a total of 90 d to observe tag loss, tissue response to tagging, and long-term survival. Levels of *Renibacterium salmoninarum* (Rs), the bacterial agent responsible for bacteria kidney disease (BKD) were also compared among treatments and between fish that died prior to the end of the holding period vs. fish that survived 90 d. Results of these comparisons were used to determine whether or not acoustic-tagged fish were more suseptable to BKD than PIT-tagged fish. Coded-wire tags were collected from all laboratory fish when present in an attempt to determine whether variations in percent survival were related to individual hatchery release groups.

Methods

Fish Collection, Transport, and Tissue Sampling

Fish allocated for long-term holding and observation were selected from groups of yearling and subyearling Chinook salmon tagged at Lower Granite Dam for evaluations of migration behavior and survival. Subsamples of 120 yearling Chinook salmon (40 AT, 40 PIT, and 40 reference) and 160 subyearling Chinook salmon (40 AT, 40 AT pilot, 40 PIT, and 40 reference) were taken for laboratory holding. Subsamples of 120 fish were taken from each of the 10 yearling release groups, for a total of 1,200 fish. Subsamples of 160 fish were taken from 9 of the 27 subyearling release groups tagged at Lower Granite Dam (over the full range of the summer tagging session) for a total of 1,440 fish.

Reference fish were collected at Lower Granite Dam, anesthetized, and handled in the same manner as acoustic-tagged fish; however, no incision, suture, or tag was placed in these fish. Following tagging, laboratory fish were held in one of two 75-L (19.8 gal) stainless steel holding tanks supplied with flow-through river water for 12-24 h. At the end of the holding period, fish were transferred (water-to-water) to a 1,817 L (480 gal) trailer tank containing saline river water (10 ppt) and transported by truck to the juvenile monitoring facility at Bonneville Dam Second Powerhouse. Mean time of transport was 6 h 14 min. Water temperatures during individual transports were kept within 1.1°C of the departure temperature by adding jugs containing frozen river water to the tank as needed. Transport temperatures ranged from 10.8 to 12.8°C during spring and from 15.6 to 20.0°C during summer.

Upon arrival at the Bonneville facility, fish were transferred (water-to-water) to 1,893-L (500 gal) circular tanks and held by transport group (e.g., 120 fish per tank in spring and 160 fish per tank in summer). In an attempt to mimic the physical conditions experienced by migrating fish, study tanks were maintained with flow-through river water at ambient temperature for 14 d. Freshwater temperature ranged from 10.6 to 21.7°C during spring and from 16.7 to 21.7°C during summer. On day 15, study tanks were converted to a closed artificial seawater system (to mimic ocean conditions), which was maintained through the remainder of the 90-d holding period. Seawater holding temperature ranged from 11.1 to 13.3°C throughout both seasons and did not vary by more than 1°C within a 24-h period.

The timing of transfer to seawater at 15 d holding was based primarily on yearling travel times (Hockersmith et al. 2007). In 2007, median travel time from Lower Granite to Bonneville Dam was 12.9 d for AT and 12.5 d for PIT-tagged yearling Chinook. Subyearling travel times during the summer migration are typically more variable (Conner et al. 2005). However, we also transferred these groups to seawater at 15 d holding for comparison purposes. For subyearling Chinook released at Lower Granite Dam, median travel time to Bonneville Dam was 24.1 d for AT and 15.5 d for PIT-tagged groups

Fish were fed ad libitum a diet consisting of a mixture of appropriately sized *BioDiet Grower*, a semi-moist pelleted commercial fish food (Bio-Oregon). Waste food and fish excrement were removed from holding tanks on a continuous basis by the self-cleaning action of flow within the tanks. Tanks were monitored for dropped tags and mortalities at least twice daily.

At the end of the 90-d holding period, surviving fish were humanely euthanized with an overdose of MS-222 (UFR Committee 2004) and weighed and measured. Gross necropsies were performed following the methods outlined by Noga (1996) to evaluate gross tissue response to tagging, such as tag encapsulation. Kidney tissue was collected from each laboratory fish and placed in individually labeled sample bags (Nasco Whirlpak, 2 oz, #B01064). These samples were frozen and transported on ice to labs at the Northwest Fisheries Science Center, Seattle, WA, for analysis. Kidney samples were processed and Rs antigen level determined for each fish in the same manner described above for migrating fish recaptured for necropsy and histological exam. Coded-wire tags were collected from the snouts of individual fish when present, and their respective codes were recorded in a database for future reference.

Data Analysis

We compared laboratory survival estimates at 14, 28, and 90 d post-treatment. Comparison at day 14 corresponded with the end of the freshwater holding phase. Comparison at day 28 was included to identify residual mortality from handling or tagging that may have been dampened by transfer into seawater or obscured by background mortality at 90 d.

Mean survival at 14, 28, and 90 d was compared among treatment groups using Fisher's LSD. A two-factor ANOVA was conducted, with replicate release date as a random factor and tag treatment as a fixed factor. Mean growth in mm (yearling and subyearling Chinook) and mean weight gain in g (subyearling Chinook) were calculated by replicate for AT and PIT-tagged fish that survived 90-d holding. Paired *t*-tests were used to compare differences between treatments and across replicates.

Paired *t*-tests were also used to compare differences in Rs antigen levels between treatments and across replicates. Levels of Rs antigen present at the time of death were compared among treatment groups both for fish that had died prematurely, and for those that survived the entire 90-d holding period. Comparisons of Rs antigen levels followed the methods described for migrating fish recaptured for necropsy and histological exam.

Differences in the percentage of PIT tags lost between treatments (AT and PIT) for spring and summer groups were evaluated statistically using chi-square tests. Tag loss was compared only for fish that survived to the end of the holding period because for those that died earlier, it was not always possible to determine whether tag loss had occurred pre- or post-mortem. Both acoustic and PIT-tag losses were determined post-mortem at the time of necropsy. Due to the small number of tags recovered from the bottom of holding tanks, it was not possible to determine the timing of tag loss. Missing tags could have been dropped through an open wound or could have been actively expelled through the body wall.

Results

Yearling Chinook Salmon

Survival—Yearling Chinook salmon exhibited a decline in survival over time (all treatments) throughout the 90-d holding period (Figure 20; Table 24). For all treatments (reference, AT, and PIT), the downward slope of the survival curve became more gradual after fish were transferred into seawater on day 15. Mortality began to accelerate again after ~56 d of holding and then steadily increased through 90 d for all treatments. Overall, AT fish experienced lower survival throughout the entire 90-d holding period than did reference and PIT-tagged fish.

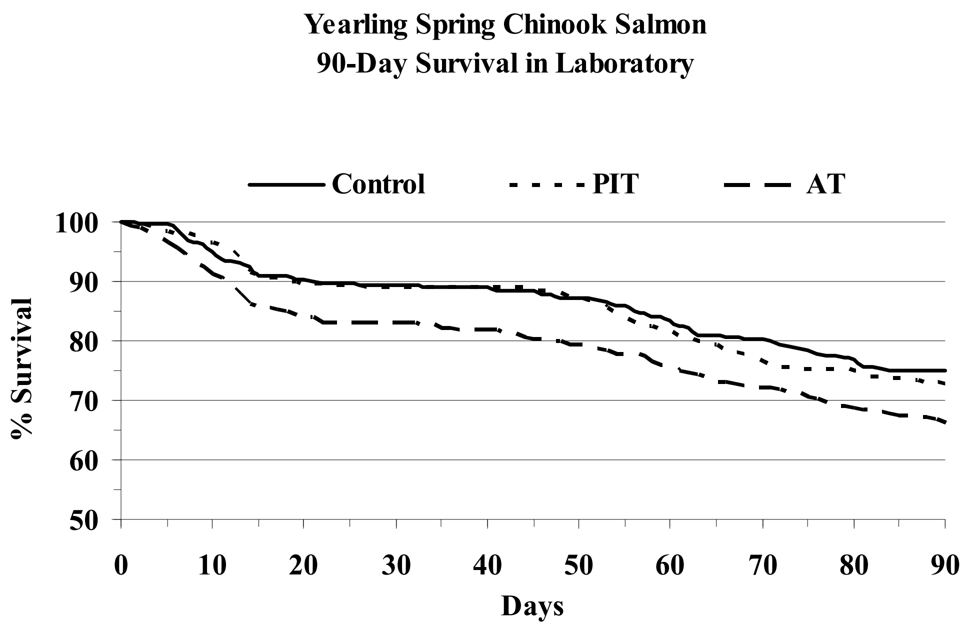


Figure 20. Percentage survival for laboratory fish by treatment through 90 d holding at Bonneville Dam.

After 14 d holding, mean survival was significantly different among laboratory study groups, with mean survival of AT fish lower than that of PIT and reference fish (P = 0.027) . After 28 d of holding, significant differences in mean survival were found among laboratory study groups, with mean survival of AT fish significantly lower than that of PIT-tagged and reference fish (P = 0.012). By 90 d holding, mean survival among these laboratory study groups was not significantly different (P = 0.159).

Table 24. Percentage survival for yearling Chinook by treatment group (reference, AT, or PIT) after 14, 28, and 90 d holding in the laboratory at Bonneville Dam. Total indicates mean by replicate date for all treatment groups combined. Pooled total indicates mean by treatment for all replicate dates combined. Mean indicates average of all replicate means. Standard errors are shown in parenthesis.

	Yearling Chinook Survival			
Treatment date	**Reference**	**AT**	**PIT-tag**	**Total**
	14 d holding			
24 Apr	0.95 (0.03)	0.95 (0.03)	0.95 (0.03)	0.95 (0.02)
25 Apr	0.90 (0.05)	0.88 (0.05)	0.97 (0.03)	0.92 (0.03)
27 Apr	0.95 (0.03)	0.88 (0.05)	0.98 (0.02)	0.93 (0.02)
30 Apr	0.68 (0.08)	0.79 (0.07)	0.84 (0.05)	0.78 (0.04)
2 May	0.95 (0.05)	0.63 (0.011)	0.74 (0.07)	0.77 (0.05)
4 May	0.98 (0.02)	0.95 (0.03)	1.00 (0.00)	0.98 (0.01)
7 May	0.88 (0.05)	0.73 (0.07)	0.83 (0.06)	0.81 (0.04)
9 May	0.98 (0.02)	0.93 (0.04)	0.93 (0.04)	0.94 (0.02)
11 May	1.00 (0.00)	0.85 (0.06)	0.95 (0.03)	0.93 (0.02)
14 May	1.00 (0.00)	0.92 (0.04)	0.98 (0.02)	0.96 (0.02)
Pooled total	0.92 (0.02)	0.86 (0.02)	0.92 (0.02)	0.90 (0.01)
Mean	0.93 (0.02)	0.85 (0.02)	0.92 (0.02)	0.90 (0.01)
	28 d holding			
24 Apr	0.95 (0.03)	0.93 (0.04)	0.95 (0.03)	0.94 (0.02)
25 Apr	0.85 (0.06)	0.88 (0.05)	0.92 (0.04)	0.88 (0.03)
27 Apr	0.95 (0.03)	0.85 (0.06)	0.98 (0.02)	0.92 (0.02)
30 Apr	0.66 (0.08)	0.74 (0.07)	0.82 (0.06)	0.74 (0.04)
2 May	0.84 (0.08)	0.53 (0.011)	0.74 (0.07)	0.71 (0.05)
4 May	0.98 (0.02)	0.95 (0.03)	1.00 (0.00)	0.98 (0.01)
7 May	0.79 (0.06)	0.70 (0.07)	0.75 (0.07)	0.75 (0.04)
9 May	0.95 (0.03)	0.88 (0.05)	0.88 (0.05)	0.90 (0.03)
11 May	0.97 (0.03)	0.83 (0.06)	0.93 (0.04)	0.91 (0.03)
14 May	1.00 (0.00)	0.87 (0.05)	0.95 (0.03)	0.94 (0.02)
Pooled total	0.89 (0.02)	0.83 (0.02)	0.89 (0.02)	0.87 (0.01)
Mean	0.89 (0.02)	0.81 (0.02)	0.89 (0.02)	0.87 (0.01)
	90 d holding			
24 Apr	0.88 (0.05)	0.75 (0.07)	0.88 (0.05)	0.83 (0.03)
25 Apr	0.75 (0.07)	0.70 (0.07)	0.38 (0.08)	0.61 (0.04)
27 Apr	0.77 (0.07)	0.60 (0.08)	0.88 (0.05)	0.75 (0.04)
30 Apr	0.45 (0.08)	0.63 (0.08)	0.49 (0.07)	0.52 (0.05)
2 May	0.68 (0.011)	0.32 (0.11)	0.44 (0.08)	0.47 (0.06)
4 May	0.78 (0.07)	0.70 (0.07)	0.95 (0.03)	0.81 (0.04)
7 May	0.57 (0.08)	0.45 (0.08)	0.63 (0.08)	0.55 (0.05)
9 May	0.90 (0.05)	0.73 (0.07)	0.85 (0.06)	0.83 (0.03)
11 May	0.79 (0.07)	0.70 (0.07)	0.85 (0.06)	0.78 (0.04)
14 May	0.82 (0.07)	0.85 (0.06)	0.93 (0.04)	0.87 (0.03)
Pooled total	0.74 (0.02)	0.66 (0.02)	0.72 (0.02)	0.71 (0.01)
Mean	0.74 (0.04)	0.64 (0.04)	0.73 (0.04)	0.70 (0.01)

Growth—At the end of the 90-d holding period, survivors were measured (FL) and weighed, and growth in mm was calculated for individual fish based on fork length at the time of tagging. Table 25 shows average growth in millimeters for yearling Chinook by tag treatment and date of tagging. For yearling Chinook that survived to the end of the 90-d holding period, average growth was 33.4 mm for AT fish (range 27.5-40.0 mm) and 37.1 mm for PIT-tagged fish (range 33.2-41.9 mm). The difference in average growth between AT and PIT-tagged fish was 3.6 mm and was significant at the 0.068 level.

Table 25. Average growth of yearling Chinook by treatment group and tagging date for fish that survived 90 days holding at Bonneville Dam. Average as reported represents the overall average by treatment of the replicates. The standard errors of each average are contained in parentheses.

	Average yearling Chinook growth (mm)	
Tagging date	AT	PIT
24 Apr	36.5 (2.5)	37.9 (2.3)
25 Apr	36.1 (2.1)	40.2 (2.7)
27 Apr	30.5 (2.9)	41.9 (1.5)
30 Apr	31.0 (2.9)	41.2 (2.6)
2 May	40.0 (5.7)	33.8 (2.5)
4 May	27.5 (2.1)	35.4 (1.8)
7 May	30.2 (3.7)	35.7 (1.9)
9 May	32.8 (2.3)	34.2 (2.2)
11 May	35.6 (2.3)	33.2 (1.7)
14 May	34.3 (2.5)	36.9 (2.1)
Average	33.4 (1.2)	37.1 (1.2)

Tag Expulsion—Yearling Chinook that survived to the end of the 90-d holding period expelled or dropped PIT tags at low rates, as shown in Table 26. The difference in PIT-tag loss between treatments was small (1.7%) but significant at the 0.064 level. One PIT tag per replicate was lost for AT groups 1, 3, 4, 6, and 7. One PIT tag was lost from a PIT-tagged fish in the first replicate. No yearling laboratory AT fish that survived to the end of the 90-d holding period expelled or dropped acoustic tags.

Table 26. Percentage of dropped or expelled tags by AT and PIT-tagged fish held 90 d at Bonneville Dam. Actual number of tags lost is in parentheses. The difference in PIT–tag loss between treatments was 1.7% (P = 0.064).

	Tag loss or expulsion (%)	
	AT fish	PIT-tagged fish
PIT tag	2.0 (5)	0.3 (1)
Acoustic tag	0.0 (0)	NA

Prevalence of *Renibacterium salmoninarum*—Of the hatchery yearling Chinook salmon held in the laboratory at Bonneville, 334 died before termination of the study. For these fish, overall ELISA values ranged from 0.060 to 3.709. Coded values for individual ELISA samples from mortalities were averaged by replicate and treatment (Table 27). No significant difference was found in BKD levels among reference, AT, and PIT-tagged mortalities (Kruskal-Wallis; P = 0.774). Coded values averaged around 2.0 across treatments.

Levels of BKD were somewhat lower for the 814 hatchery yearling Chinook salmon that did not die before termination of the study. Overall ELISA values ranged from 0.054 to 3.304. Mean coded values for individual ELISA samples were calculated by replicate and treatment (Table 28). No significant difference was found in BKD levels among reference, AT, and PIT-tagged fish (Kruskal-Wallis; P = 0.993). Coded levels averaged 1.4 across treatments.

Table 27. Hatchery yearling Chinook salmon ELISA coded values averaged by replicate and treatment for fish that died during 90-day holding at Bonneville juvenile monitoring facility.

Treatment group	Replicate	Sample	ELISA Code Avg
Reference	1	5	2.80
	2	10	1.90
	3	9	2.44
	4	21	2.00
	5	6	2.17
	6	9	2.56
	7	18	1.89
	8	4	1.75
	9	8	1.88
	10	6	1.33
AT	1	10	2.20
	2	11	2.09
	3	16	2.25
	4	14	1.93
	5	13	1.62
	6	12	2.75
	7	22	2.00
	8	11	1.27
	9	12	1.25
	10	6	1.50
PIT	1	5	2.20
	2	24	2.79
	3	5	2.00
	4	23	2.39
	5	22	2.23
	6	2	1.00
	7	15	2.20
	8	6	1.50
	9	6	1.00
	10	3	1.33
		Total	Average
Reference		96	2.1
AT		127	1.9
PIT		111	1.9

Table 28. Hatchery yearling Chinook salmon coded values averaged by replicate and treatment for fish held at Bonneville juvenile monitoring facility and still alive at the termination of the study.

Treatment	Replicate	Fish (N)	ELISA Code Avg
Reference	1	35	1.5
	2	30	1.6
	3	30	1.8
	4	17	1.6
	5	13	1.2
	6	31	1.2
	7	24	1.6
	8	36	1.0
	9	30	1.1
	10	28	1.2
AT	1	30	1.6
	2	28	1.5
	3	24	2.0
	4	24	1.9
	5	6	1.2
	6	28	1.3
	7	18	1.4
	8	29	1.0
	9	28	1.1
	10	33	1.1
PIT	1	35	1.5
	2	15	1.5
	3	35	1.7
	4	22	1.8
	5	17	1.2
	6	38	1.3
	7	25	1.7
	8	34	1.0
	9	34	1.0
	10	37	1.1
		Total	Average
Reference		274	1.4
AT		248	1.4
PIT		292	1.4

Influence of Hatchery Fish—All yearling Chinook held at Bonneville were scanned for CWTs post-mortem. Overall, CWTs were identified in nearly 16% of the laboratory fish (180 tags), representing 10 hatchery groups. Table 29 shows the number of CWTs collected by hatchery of origin along with proportions of CWT-tagged fish by hatchery that had either low, medium, or high BKD ELISA values. Figure 21 shows comparative survival for yearling laboratory fish with CWTs by hatchery of origin. Overall, our CWT sample numbers were too low for meaningful statistical analysis.

Survival for CWT-tagged yearling fish ranged from 0.73 to 1.00, with one outlier at 0.00 (all 4 CWT fish from Lyons Ferry Hatchery died). Lyons Ferry Hatchery group also had the largest proportion of fish with high ELISA values (0.75). The proportion of fish from other hatchery groups with high ELISA values ranged from 0.00 to 0.44.

Table 29. Survival rates of yearling laboratory fish with CWTs by hatchery of origin. The percentage of these fish by hatchery that had either a low, medium, or high ELISA value is also indicated along with the total number of CWTs collected.

		ELISA value			
Hatchery Origin	Survival	Low	Med	High	Number of CWTs
Clearwater	0.93	0.44	0.37	0.19	27
Dworshak	0.80	0.66	0.20	0.14	35
Kooskia	0.88	0.63	0.13	0.25	8
Lookingglass	0.84	0.66	0.12	0.22	50
Lyons Ferry	0.00	0.25	0.00	0.75	4
McCall	0.73	0.55	0.36	0.09	11
Pahsimeroi	0.75	1.00	0.00	0.00	4
Rapid River	0.75	0.56	0.00	0.44	16
Sawtooth	0.73	0.82	0.00	0.18	11
Umatilla	1.00	1.00	0.00	0.00	1
Unknown	1.00	1.00	0.00	0.00	3

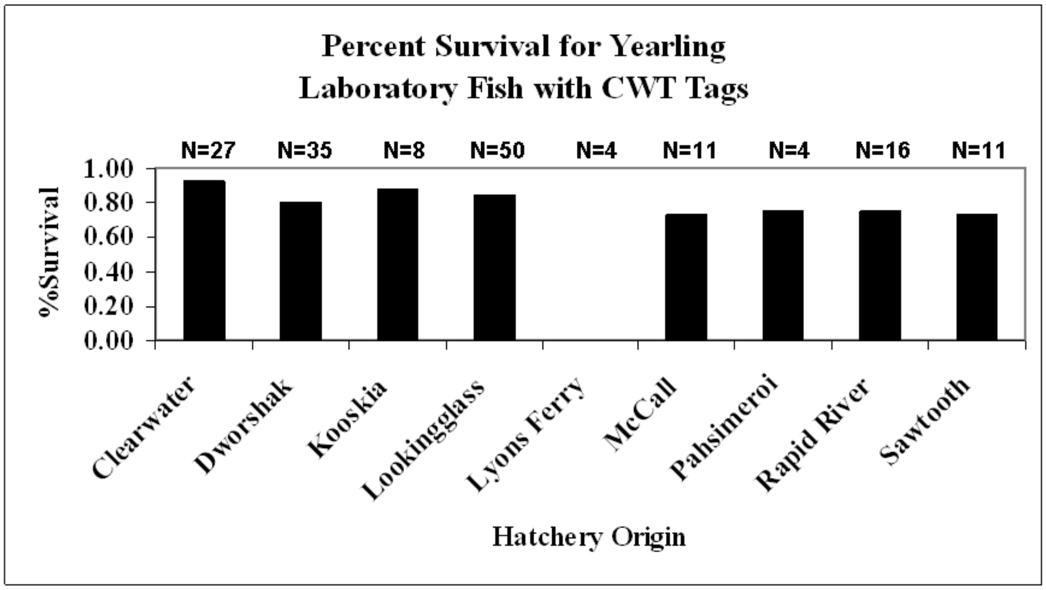


Figure 21. Percent survival during 90-d holding at Bonneville Dam for yearling Chinook with CWTs by hatchery of origin. The actual number of CWTs collected by hatchery is noted above each bar.

It is worth noting that approximately 94.8% of Lyons Ferry Hatchery fish released above Lower Granite Dam were marked with CWTs (Fish Passage Center). However, only 4 of the 1,149 fish sampled for holding in the Bonneville laboratory were CWT-tagged fish from Lyons Ferry Hatchery. Assuming equal survival rates to Lower Granite Dam between fish with CWTs and non-tagged fish, the total number of Lyons Ferry Hatchery fish in our laboratory sample (marked and unmarked) would have been about 4 fish. Based on this estimate, it is likely that Lyons Ferry fish represented only about 0.4% of the total number of yearling Chinook subsampled for laboratory evaluations.

Subyearling Chinook Salmon

Survival—A sharp decline in survival was observed from day 0 to day 18 in subyearling Chinook belonging to both the AT and AT-pilot groups (Figure 22; Table 30). After day 18, mortality continued at a lower rate in these fish until the end of the study. In contrast, the survival curve for both reference and PIT-tagged fish exhibited a shallow decline throughout the entire holding period. The relationship in comparative survival among groups remained constant throughout the entire 90-d holding period.

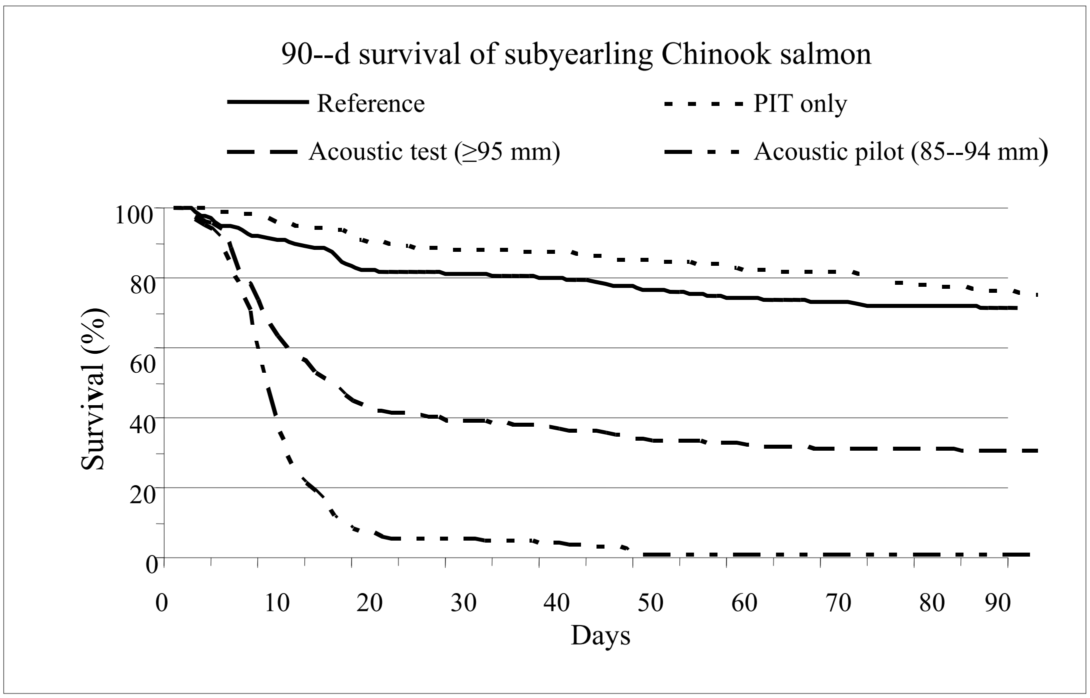


Figure 22. Percent survival for reference, AT, AT pilot, and PIT-tagged fish by treatment during 90-d holding at Bonneville Dam.

Mean survival among laboratory groups after 14 d holding was significantly different (ANOVA, $P = 0.00$). Further testing based on Fisher's LSD revealed that mean survival for AT fish was significantly lower than that of PIT-tagged and reference fish, and that mean survival for AT pilot fish was significantly lower than that of the other three groups. Mean survival between PIT-tagged and reference groups was not significantly different. Significant differences among survival means continued to be observed throughout the entire 90-d holding period.

Table 30. Survival of subyearling Chinook by treatment group after 14, 28, and 90 d holding in the laboratory at Bonneville Dam. Total indicates mean by replicate date for all treatment groups combined. Pooled total indicates mean by treatment for all replicate dates combined. Mean indicates average of all replicate means. Standard errors are shown in parenthesis.

	Subyearling Chinook survival				
Treatment date	Reference	AT (≥ 95 mm)	AT pilot (85-94 mm)	PIT	Total
			14 d holding		
6 Jun	0.98 (0.02)	0.92 (0.04)	0.10 (0.05)	1.00 (0.00)	0.75 (0.03)
12 Jun	0.98 (0.02)	0.68 (0.07)	0.10 (0.05)	1.00 (0.00)	0.69 (0.04)
15 Jun	0.97 (0.03)	0.38 (0.08)	0.28 (0.07)	0.95 (0.03)	0.65 (0.04)
19 Jun	0.95 (0.03)	0.43 (0.08)	0.13 (0.05)	0.97 (0.03)	0.62 (0.04)
21 Jun	0.80 (0.06)	0.45 (0.08)	0.11 (0.05)	0.98 (0.02)	0.60 (0.04)
26 Jun	0.95 (0.03)	0.68 (0.07)	0.40 (0.08)	0.93 (0.04)	0.74 (0.03)
28 Jun	0.87 (0.05)	0.73 (0.07)	0.34 (0.08)	0.98 (0.02)	0.73 (0.04)
5 Jul	0.78 (0.07)	0.39 (0.08)	0.13 (0.05)	0.87 (0.05)	0.54 (0.04)
11 Jul	0.73 (0.07)	0.13 (0.05)	0.00 (0.00)	0.83 (0.06)	0.49 (0.04)
Pooled total	0.89 (0.02)	0.53 (0.03)	0.19 (0.02)	0.94 (0.01)	0.65 (0.01)
Mean	0.88 (0.04)	0.53 (0.04)	0.18 (0.04)	0.94 (0.04)	0.65 (0.04)
			28 d holding		
6 Jun	0.95 (0.03)	0.69 (0.07)	0.03 (0.03)	0.95 (0.04)	0.66 (0.04)
12 Jun	0.98 (0.02)	0.51 (0.08)	0.08 (0.04)	0.95 (0.04)	0.63 (0.04)
15 Jun	0.82 (0.06)	0.28 (0.07)	0.10 (0.05)	0.90 (0.05)	0.53 (0.04)
19 Jun	0.93 (0.04)	0.35 (0.08)	0.05 (0.03)	0.95 (0.04)	0.57 (0.04)
21 Jun	0.73 (0.07)	0.28 (0.07)	0.08 (0.05)	0.95 (0.03)	0.52 (0.04)
26 Jun	0.95 (0.03)	0.61 (0.08)	0.23 (0.07)	0.86 (0.05)	0.66 (0.04)
28 Jun	0.79 (0.06)	0.58 (0.08)	0.08 (0.04)	0.98 (0.02)	0.61 (0.04)
5 Jul	0.68 (0.07)	0.32 (0.08)	0.03 (0.03)	0.85 (0.06)	0.47 (0.04)
11 Jul	0.51 (0.08)	0.10 (0.05)	0.00 (0.00)	0.60 (0.08)	0.35 (0.04)
Pooled total	0.81 (0.02)	0.41 (0.03)	0.08 (0.01)	0.89 (0.02)	0.56 (0.01)
Mean	0.82 (0.03)	0.41 (0.03)	0.07 (0.03)	0.89 (0.03)	0.56 (0.03)
			90 d holding		
6 Jun	0.88 (0.05)	0.62 (0.08)	0.03 (0.03)	0.92 (0.04)	0.62 (0.04)
12 Jun	0.93 (0.04)	0.46 (0.08)	0.03 (0.03)	0.85 (0.06)	0.57 (0.04)
15 Jun	0.59 (0.08)	0.15 (0.06)	0.03 (0.03)	0.80 (0.06)	0.39 (0.04)
19 Jun	0.83 (0.06)	0.35 (0.08)	0.00 (0.00)	0.87 (0.05)	0.51 (0.04)
21 Jun	0.68 (0.07)	0.18 (0.06)	0.03 (0.03)	0.83 (0.06)	0.44 (0.04)
26 Jun	0.85 (0.06)	0.46 (0.08)	0.13 (0.05)	0.74 (0.07)	0.55 (0.4)
28 Jun	0.72 (0.07)	0.45 (0.08)	0.03 (0.03)	0.98 (0.02)	0.55 (0.04)
5 Jul	0.58 (0.08)	0.21 (0.07)	0.00 (0.00)	0.67 (0.08)	0.37 (0.04)
11 Jul	0.37 (0.08)	0.08 (0.04)	0.00 (0.00)	0.33 (0.07)	0.22 (0.04)
Pooled total	0.71 (0.02)	0.33 (0.02)	0.03 (0.01)	0.77 (0.02)	0.47 (0.01)
Mean	0.71 (0.04)	0.33 (0.04)	0.03 (0.04)	0.77 (0.04)	0.47 (0.04)

Growth—In subyearling Chinook that survived to the end of the 90-d holding period, mean growth was 29.5 mm for AT fish (range 17.7-39.5) and 34.0 mm for PIT-tagged fish (range 27.6-40.0; Table 31). The mean difference in growth between AT and PIT-tagged fish was 4.5 mm, and was significant at the 0.061 level.

Mean weight gain for subyearling Chinook surviving to the end of the 90-d holding period was 21.2 g for AT fish (range 10.3-33.0 g) and 24.6 g for PIT-tagged fish (range 20.3-28.5 g; Table 31). The mean difference in weight gain between AT and PIT-tagged fish was 3.4 g and was not significant ($P = 0.246$).

Table 31. Mean growth in length and weight for subyearling Chinook by treatment group (AT and PIT-tagged fish) and treatment date for laboratory fish that survived 90 d of holding at Bonneville Dam. Means are overall mean by treatment of the replicate means.

	Subyearling Chinook salmon growth	
	AT	PIT
Treatment date	Mean increase in length (mm)	
6 Jun	28.2 (11.2)	33.3 (9.2)
12 Jun	31.3 (8.0)	27.6 (9.7)
15 Jun	40.0 (11.4)	34.6 (15.0)
19 Jun	36.6 (11.1)	40.0 (8.0)
21 Jun	25.3 (13.3)	35.5 (5.3)
26 Jun	32.4 (13.2)	36.1 (10.7)
28 Jun	27.8 (14.1)	33.8 (9.5)
5 Jul	26.4 (11.7)	32.2 (9.4)
11 Jul	17.7 (17.7)	32.9 (17.8)
Mean	29.5 (1.5)	34.0 (1.5)
	Mean increase in weight (g)	
6 Jun	19.2 (9.6)	20.3 (6.8)
12 Jun	22.3 (8.2)	20.6 (8.4)
15 Jun	33.0 (16.6)	20.6 (7.3)
19 Jun	23.4 (5.7)	28.5 (8.6)
21 Jun	17.0 (9.6)	27.5 (6.9)
26 Jun	23.3 (11.2)	25.4 (9.6)
28 Jun	20.9 (11.3)	26.0 (8.9)
5 Jul	21.0 (11.7)	24.5 (9.9)
11 Jul	10.3 (10.1)	27.8 (21.8)
Mean	21.2 (1.9)	24.6 (1.9)

Tag Expulsion—Subyearling laboratory fish that survived to the end of the 90-d holding period expelled or dropped PIT tags at the following rates: AT fish 3.4% (4 fish), AT pilot fish 0.0% (0 fish), and PIT-tagged fish 0.0% (0 fish; Table 32). From replicates 11, 15, 16, and 17, AT fish lost one PIT tag each. The difference in PIT-tag loss between AT and PIT-tagged fish was 3.4%, and was significant (*P* = 0.002). Only 10 AT pilot fish survived to study termination; therefore, due to small sample size, we did not compare tag loss in this group to the other treatment groups.

Subyearling laboratory fish that survived to the end of the 90-d holding period expelled or dropped acoustic tags as follows: AT fish 7.6% (9 fish), AT pilot fish 0.0% (0 fish). Acoustic tags were lost from fish in replicates 11 (4 fish), 12 (1 fish), 16 (1 fish), 17 (1 fish), and 18 (2 fish). No AT fish that survived to termination lost both types of tags.

Table 32. Percentage of tags dropped or expelled by treatment group (AT, AT pilot, and PIT) from subyearling Chinook laboratory fish during the 90-d holding period at Bonneville Dam. Actual number of tags lost is in parentheses. Chi-square testing revealed a significant difference in PIT tag loss between AT and PIT-tagged fish (*P* = 0.002).

	Lost or expelled tags (%)		
	AT	AT pilot (85-94 mm)	PIT
PIT tags	3.4 (4)	0.0 (0)	0.0 (0)
Acoustic tags	7.6 (9)	0.0 (0)	NA

Prevalence of *Renibacterium salmoninarum*—Compared to the yearling study fish, BKD levels as measure by ELISA were somewhat lower, but treatment comparisons were similar, for the 695 hatchery subyearling Chinook salmon that died before termination of the holding study. Overall ELISA values ranged from 0.055 to 2.264. Mean coded ELISA values are shown by replicate and treatment in Table 33. No significant difference in ELISA levels was found among reference, AT, AT pilot, and PIT-tagged fish (Kruskal-Wallis; *P* = 0.584). Mean coded ELISA values were 1.3 for reference fish, 1.2 for AT and AT pilot fish, and 1.3 for PIT-tagged fish.

For the 663 hatchery subyearling Chinook salmon held at Bonneville Dam that did not die before termination of the study, ELISA values were low, ranging from 0.040 to 0.240 (with two outliers at 0.308 and 0.419). Since ELISA values for all but a few samples were considered to be low, no statistical analysis was conducted to evaluate differences among tag treatment groups.

Table 33. Hatchery subyearling Chinook salmon ELISA coded values for RS antigen averaged by replicate and treatment for mortalities of fish held at the juvenile monitoring facility at Bonneville Dam.

Treatment	Replicate	Fish (N)	ELISA Code Avg
Reference	11	5	1.0
	12	3	1.3
	13	16	1.1
	14	7	1.4
	15	13	1.2
	16	6	1.3
	17	11	1.0
	18	15	1.6
	19	26	1.3
AT	11	15	1.1
	12	22	1.1
	13	30	1.3
	14	24	1.0
	15	30	1.1
	16	18	1.2
	17	22	1.5
	18	29	1.2
	19	32	1.3
AT pilot	11	38	1.3
	12	37	1.2
	13	35	1.1
	14	35	1.1
	15	35	1.1
	16	30	1.1
	17	34	1.4
	18	33	1.4
	19	15	1.5
PIT	11	3	1.0
	12	6	1.3
	13	8	1.1
	14	5	1.0
	15	7	1.1
	16	11	1.0
(not used)	17	1	1.0
	18	12	1.4
	19	26	1.3
		Total	Mean
Reference		102	1.3
AT		222	1.2
AT Pilot		292	1.2
PIT		79	1.1

Influence of Hatchery Fish—All subyearling laboratory fish were scanned for CWTs post-mortem. Overall, CWTs were identified in 26% of the laboratory fish (371 tags), representing four hatcheries. Table 34 shows the number of CWT tags collected by hatchery of origin along with the percentage of CWT-tagged fish by hatchery that had either a low, medium, or high BKD ELISA value. Although we collected approximately twice as many CWTs from subyearling as from yearling Chinook, sample numbers of subyearlings were still too low for meaningful analysis.

Table 34. Survival rates of subyearling laboratory fish with CWTs by hatchery of origin. The percent of CWT-tagged fish by hatchery that had either a low, medium, or high BKD ELISA value is also indicated along with the total number of tags collected.

		BKD ELISA			
Hatchery Origin	Survival	low	med	High	Number of CWTs
Lyons Ferry	0.95	0.99	0.00	0.01	138
Nez Perce	0.97	0.99	0.00	0.01	193
Umatilla	0.69	0.97	0.00	0.03	36
Oxbow-ID	1.00	1.00	0.00	0.00	3
Unknown	0.00	1.00	0.00	0.00	1

Survival for CWT-tagged subyearling fish ranged from 0.69 to 1.00 with one outlier at 0.00. Subyearling fish from Umatilla Hatchery had lower survival (0.69) than fish from the other three hatcheries (0.95-1.00). An overwhelming majority (0.97-1.00) of CWT-tagged hatchery subyearling Chinook had ELISA values that were characterized as low.

Overall, 48.8% of the Umatilla Hatchery subyearling Chinook released to the river were marked with CWTs (Fish Passage Center). Of the 1,407 fish sampled from the laboratory, 36 were CWT-tagged fish from the Umatilla Hatchery. Assuming equal survival to Lower Granite Dam between fish with CWTs and non-tagged fish, we estimate that the total number of Umatilla Hatchery fish in our laboratory sample (marked and unmarked) was about 74 fish. Based on this estimate, it is likely that Umatilla Hatchery fish represented approximately 5.2% of our total subyearling laboratory group.

Discussion

Yearling Chinook salmon held in the laboratory fared better overall than their counterparts migrating in the river. Relative survival between tag treatments (AT/PIT) was 0.92 for fish held in the laboratory at 14 d post-tagging, compared to 0.79 for migrating fish arriving at Bonneville Dam at 12 d post-tagging. Similar to our inriver migrating groups, differences in survival between tag treatment groups diverged through approximately 12 d post-treatment. By day 14, the majority of migrating fish had passed the final detection site at Bonneville Dam, precluding any further survival comparison between the two groups based on PIT-tag detections.

Up until the point at which laboratory groups were transferred into seawater, we observed a steady decline in survival among all treatment groups, and progressively larger survival differences between the AT and PIT-tagged fish. The survival curve for the reference group followed that of the PIT-tagged group closely. Once fish were transferred to seawater, however, the steep downward sloping of the survival curve, which had been observed from d 0-16 in all groups, started to level off. Differences in survival between AT, PIT, and reference fish were thereafter noticeably less.

It is possible that fish received a therapeutic benefit from the seawater transfer (Noga 2000), and that this benefited the AT fish to a greater extent than the others. It is equally plausible that the observed decrease in the rate of mortality in AT fish relative to the other treatment groups was due to a "tag effect" or "handling effect" that had run its course. Most likely, our observations can be attributed at least in part to both explanations. Additionally, cumulative mortality in the reference and PIT-tagged groups by 90 d likely diminished the statistical power of the test for comparative survival, resulting in a difference in mean survival among groups that was no longer significant at study termination. The magnitude of the difference in growth between AT and PIT-tagged fish held at Bonneville Dam, although significant at the 0.068 level, may also have been influenced by higher mortality in the AT fish relative to the PIT-tagged fish.

Yearling Chinook salmon that survived to the end of the 90-d holding period were observed to lose PIT tags at slightly unequal rates, with 2% tag loss in AT fish and 0.3% in PIT-tagged fish (AT-PIT= 1.7%; $P = 0.060$). This is not surprising, as histopathology results from SbyC fish recaptured at McNary and Bonneville Dams indicated that wound/incision healing had advanced at a slower rate in AT than in PIT-tagged fish. A delay in incision healing would predispose fish to PIT-tag loss.

Similar to results observed for migrating fish recaptured using SbyC, a comparison of Rs antigen between laboratory treatment groups showed no evidence that AT fish were more predisposed to developing BKD than either PIT or reference fish. This was evident in both the short-term (mortalities) and long-term (fish surviving to study termination) study fish. In CWT fish, although survival as well as Rs antigen levels differed by hatchery of origin, there was no evidence that overall laboratory survival across replicates was biased or negatively influenced by one or more hatchery group.

For subyearling Chinook salmon, survival results from the long-term holding study supported results from field evaluations. In the laboratory, we observed significant differences in survival for both AT and AT pilot fish compared to PIT and reference fish throughout the holding period. Furthermore, survival of AT pilot fish was significantly lower than that of AT fish. In addition, although we observed a more or less steady but shallow decline in survival for the PIT and reference fish over time, we observed a sharp decline in survival for both AT and AT pilot fish from 0 to 18 d post-treatment. As such, although the magnitude of the difference in relative survival between AT and PIT-tagged fish continued to grow throughout the holding period, the majority of this difference was apparent at approximately 18 d.

Similar to the spring portion of this study, it appears that by 18 d of holding, either the tag effect had largely run its course, or treatment fish had received a survival benefit from transfer to seawater, with AT fish benefiting to a greater extent relative to PIT and reference fish. In comparison, migrating AT fish were just passing McNary Dam at approximately 2 weeks post-release in 2007, and would have required another 2 weeks to reach ocean seawater. Also similar to the yearling fish, subyearling fish appeared to fare better in the laboratory than inriver. Relative survival for subyearling Chinook salmon held in the laboratory at 14 d post-tagging was 0.56 compared to 0.41 for their cohorts passing McNary Dam.

Unlike the yearling Chinook groups, there was a trend towards higher laboratory survival over time for PIT-tagged subyearling Chinook compared to reference fish. This may suggest that a component of the overall tag effect observed in summer was related to the increased handling or extra anesthetic burden placed on AT fish.

In addition to differential survival, a significant difference in PIT-tag loss was observed in the laboratory for subyearling Chinook that survived to termination. A 7.6% rate of acoustic-tag loss was also observed in these fish. If we assume that fish migrating inriver experience similar rates of tag loss, than we must also assume that survival estimates for AT fish based exclusively on either AT- or PIT-tag detections would be negatively biased. Of AT fish that survived 90 d, none lost both types of tags.

Finally, based on CWTs and ELISA testing there was no evidence that survival estimates for the subyearling laboratory fish were negatively biased by fish from one or more hatchery groups.

CONCLUSIONS AND RECOMMENDATIONS

Recent laboratory studies have shown little to no difference in survival and performance between juvenile Atlantic and Pacific Salmon tagged with acoustic transmitters and those injected with PIT tags for tag burdens in the range of 6.7-8% by weight (La Croix et al. 2004; Brown et al. 2007b; Anglea et al. 2004). Fork length of these study fish varied considerably, from a larger range of 122-198 mm (La Croix et al. 2004; Anglea et al. 2004) to smaller ranges of 93-126 mm for subyearlings and 98-152 mm for yearlings (Brown et al. 2007b).

In field studies as well, similar survival rates were observed between paired releases of AT and PIT-tagged yearling Chinook salmon (Skalski et al. 2003, 2005) from Wells and Rocky Reach Dams to Rock Island Dam on the Columbia River. In 2003, the tag burdens of these AT fish ranged from approximately 2.7 to 4% by weight, while median length of fish in each replicate release group ranged from 156 to 211 mm (Skalski et al. 2003). In 2004, the tag burdens of AT tagged fish ranged from 1.3 to 4.6% (mean 2.5%; Skalski et al. 2004), and mean fork length ranged from 110 to 225 mm (median 175 mm).

These results, which encompassed both laboratory and field evaluations, and which also encompassed a broad size-range for Chinook salmon, appeared promising for further development of acoustic telemetry systems. We thus attempted to examine relative survival between AT and PIT-tagged yearling and subyearling Chinook salmon as they migrated downstream past Snake and Columbia River dams.

In 2006, we conducted a pilot study to examine the effects of acoustic tagging on yearling Chinook salmon. However, results for river-run fish were inconclusive due to the lack of repetition among release groups and inadequate sample sizes of acoustic-tagged fish (study tags were not delivered in time for the spring migration). Therefore, we expanded this work in 2007 to include both field and laboratory experiments to identify differences in behavior, survival, growth, and tag loss. Yearling and subyearling Chinook salmon were surgically implanted with acoustic transmitters and PIT tags and their performance in the field and laboratory was compared to that of cohorts injected with only a PIT tag. In addition, diagnostic work was performed on actively migrating and laboratory fish to determine the etiology behind any observed differences in survival or performance. Major findings by life history type from field, diagnostic, and laboratory evaluations are summarized below.

Yearling Chinook Salmon

1. Differences in detection probability between AT and PIT-tagged fish were evident at the first downstream detection site (~60 km from release). Detection probability at Little Goose Dam was significantly greater for AT than for PIT-tagged fish (AT - PIT = 0.03; P = 0.004), based on adjusted detection data (PIT + AT detections). Conversely, PIT-tagged fish were more likely to be detected at McNary and Bonneville Dams by a difference of 0.03 (P = 0.018 and P = 0.010 respectively) based on adjusted detection data.

2. Travel time from Lower Granite Dam to each downstream detection site was similar between AT and PIT-tagged fish, although a trend of longer travel time for AT fish was apparent. A significant difference in mean travel time between tag treatments was found only at John Day Dam (AT - PIT = 0.5 d; P = 0.041).

3. Estimates of relative survival from Lower Granite to Little Goose Dam did not differ significantly (AT/PIT ≈ 1.0). However, relative survival to Lower Monumental Dam was 1.05, and was significantly higher for AT than PIT-tagged fish at the 0.080 level. Survival from Lower Granite to Ice Harbor Dam was similar between tag treatments. At McNary Dam, relative survival was 0.92, and was significantly higher for PIT than AT fish at the 0.054 level. This trend in relative survival continued through John Day (0.86; P = 0.001) and Bonneville Dam (0.79; P = 0.001).

4. Preliminary results suggest that relative survival (AT/PIT) is likely lower for smaller fish. Further analyses are needed to determine whether there is a size-dependent tag effect within the size range tested.

5. Initial covariate analyses performed to identify significant environmental and biological factors that may have been related to the tag effects observed were inconclusive due to the presence of co-linearity among several of the factors tested. (Appendix F). Additional covariate analyses are needed.

6. The overall mean PIT-tag recovery from upriver bird colonies was 0.9% for AT fish and 1.0% for PIT-tagged fish, and the difference between means was not significant. From estuary PIT-tag monitoring, detection rates were 3.3% for AT fish and 2.7% for PIT-tagged fish. Similar to the upriver comparison, the difference between means was not significant.

7. Gross necropsy of actively migrating fish recaptured at McNary and Bonneville Dams revealed several notable trends. In general, fish collected at downstream locations tended to have less adipose tissue (visible fat) than fish observed at release. At both downstream examination locations, PIT-tagged fish had more adipose tissue

and had a higher percentage of stomachs containing food than AT fish. Gross visible liver abnormalities were more prevalent in AT than in PIT-tagged fish, and the difference was significant at the 0.095 level.

8. Comparative tissue analyses through histological exam revealed significant differences between AT and PIT-tagged fish in three general categories, including nutritional condition, peritoneal inflammation and incision (AT) or injection site (PIT) healing. Indicators of nutritional condition were not consistent in direction and therefore did not support a trend for either treatment group relative to the other.

   Parameters examined to evaluate healing and inflammation both at the incision site and within the peritoneal cavity showed more evidence of inflammation in AT than PIT-tagged fish. Healing had progressed further in PIT-tagged compared to AT fish at both downstream dam where fish were recaptured. Additionally, a larger percentage of AT fish compared to PIT-tagged fish were observed with splenic congestion (an indicator of stress) at McNary Dam. Analysis by size class for fish (AT and PIT combined) recaptured at McNary Dam revealed a clear pattern in the amount of mesenteric adipose tissue present, with larger fish having more fat. At Bonneville Dam, fish smaller at tagging were more likely to have poor incision apposition, than fish larger at the time of tagging.

9. Estimated Rs antigen (BKD) levels in hatchery Chinook salmon, as measured by ELISA, ranged from 0.070 to 0.131 for fish sampled at Lower Granite Dam prior to tagging. Rs antigen values were similarly low in hatchery yearling Chinook recaptured at McNary (range 0.070-0.133; 1 outlier at 0.463) and Bonneville Dam (range 0.068 to 0.298, 1 outlier at 1.613). Since ELISA values for all but a few fish were considered low, no statistical analyses were conducted to evaluate differences between sites or among treatment groups.

10. After 14 d laboratory holding, mean survival of AT fish was significantly less than that of PIT and reference fish (P = 0.027). This difference persisted and continued to be significant (P = 0.012) at 28 d. By 90 d of holding, although the trend among treatment groups persisted, differences were no longer significant (α = 0.10). There was no difference in survival between PIT-tag and reference groups throughout holding. Among the fish that survived to 90 d, the mean difference in growth between AT and PIT-tagged fish of 3.6 mm was significant at the 0.068 level.

11. No yearling laboratory fish that survived to the end of the 90 d holding period expelled or dropped acoustic tags. In yearling Chinook surviving to 90 d, AT fish lost PIT tags at a rate of 2.0% (n = 5 tags), while PIT-tagged fish lost PIT tags at a rate of 0.3% (n = 1). The difference in PIT-tag loss between the two groups was significant at the 0.064 level.

12. Overall ELISA values for yearling fish that died before termination of the laboratory holding study ranged from 0.060 to 3.709. No significant difference was found in Rs antigen levels among treatment groups ($P = 0.774$). ELISA values for laboratory fish that survived to termination ranged from 0.054 to 3.304. Significance testing revealed no difference in Rs levels between the different treatment groups ($P = 0.993$).
13. Evidence from CWTs collected from laboratory yearling fish indicated that no single hatchery group contributed obviously compromised fish to our study in numbers sufficient to alter the results.

Subyearling Chinook Salmon

1. In comparisons of detection probability based on both AT and PIT detections, mean detection probability was significantly greater for AT than PIT-tagged fish at Little Goose Dam (AT - PIT = 0.11, $P = 0.001$). There was no significant difference in mean detection probabilities between groups at McNary Dam. We were unable to estimate reliable probabilities of detection at Lower Monumental, Ice Harbor, John Day, and Bonneville Dams due to insufficient detection numbers for AT fish.

2. Due to the small number of detections for subyearling Chinook belonging to the AT pilot group (85-94 mm FL), we did not attempt to estimate detection probabilities or survival estimates for these fish as they migrated downstream. The small number of detections was presumably due to high mortality in this group.

3. Mean survival from Lower Granite Dam to both Little Goose ($P = 0.003$) and McNary Dam ($P = 0.001$) was significantly higher for PIT-tagged than AT subyearling Chinook.

4. Travel time from Lower Granite Dam to Little Goose, Lower Monumental, Ice Harbor, and McNary Dam was significantly longer for AT than PIT-tagged subyearling Chinook ($\alpha = 0.05$).

5. Preliminary results suggest that relative survival (AT/PIT) is likely lower for smaller fish. Further analyses are needed to determine whether there is a size-dependent tag effect within the range tested.

6. Initial covariate analyses performed to identify significant environmental and biological factors that may have been related to tag effects observed were inconclusive due to the presence of co-linearity among several of the factors tested (Appendix F). Further covariate analyses are needed.

7. For subyearling Chinook released before 30 June, overall mean PIT-tag recovery from upriver bird colonies was 1.3% for AT fish and 1.7% for PIT-tagged fish, and the difference was not significant. From estuary monitoring, PIT-tag detection rates were 2.5% for AT fish and 2.0% for PIT-tagged fish. Similar to the upriver comparison, the difference between these means was not significant.

8. Gross necropsy of subyearling Chinook recaptured at Bonneville Dam revealed a few notable observations. Similar to the yearling fish, in general, migrating subyearlings recaptured at downstream locations tended to have less adipose (visible fat) than fish observed at release. At Bonneville Dam, PIT-tagged fish had more adipose than AT fish. Liver and kidney discoloration and/or abnormalities were more prevalent in fish sampled at Bonneville Dam and more prevalent in AT than PIT-tagged fish. However, based on gross necropsy, no significant differences were found in comparisons by treatment.

9. For subyearling Chinook, significant histological differences between tag treatment groups generally fell into the categories of peritoneal inflammation and healing at the incision or injection site. A higher percentage of AT than PIT-tagged fish had chronic inflammatory changes within the peritoneal cavity at the site of the incision. Healing at the incision/injection site was more advanced in PIT-tagged fish. Analysis by size class for all fish sampled at Bonneville Dam revealed a clear pattern across all sizes for the presence/absence of liver lymphocytic infiltrates. These inflammatory cells were observed more often in smaller fish compared to larger fish. Mesenteric fat was more prevalent at Bonneville for larger fish at tagging. Incision adhesions were also more prevalent in larger fish at tagging. Kidney tubule myxosporea were observed more often in smaller fish.

10. Baseline Rs antigen levels measured by ELISA from subyearling Chinook sampled at Lower Granite Dam prior to tagging ranged from 0.070 to 0.213. Similarly, ELISA values were low in subyearling Chinook recaptured at Bonneville Dam from both tag treatments, ranging from 0.078 to 0.442, with a median value of 0.095. Since ELISA values for all but a few fish were considered low, no statistical analysis was conducted to evaluate differences between detection sites or among treatment groups.

11. In the laboratory holding study, mean survival of AT fish was significantly lower than that of PIT and reference fish after 14 d ($P = 0.001$). Mean survival of AT pilot fish was significantly lower than that of the other three treatment groups ($P = 0.000$). These differences persisted and continued to be significant at 28 and 90 d ($P \leq 0.050$). Between AT and PIT-tagged fish that survived to 90 d, the mean difference in growth was 4.5 mm and was significant at the 0.061 level. The mean difference in weight gain for these fish was 3.4 g and was not significant ($\alpha = 0.10$).

12. Subyearling laboratory AT fish that survived to the end of the 90-d holding period expelled or dropped acoustic tags at the rate of 7.6% (n = 9 tags), and PIT-tag loss in these fish was 3.4% (n = 4 tags). No acoustic or PIT-tag loss was observed in AT pilot fish that survived to termination. Tag loss in PIT-tagged fish was 0.3% (n = 1) for fish that survived to termination. The difference in PIT tag loss between AT and PIT-tagged fish was significant ($P = 0.002$).

13. Overall, BKD ELISA values for laboratory fish that died before termination of the holding study ranged from 0.055 to 2.264. No significant difference were found in Rs antigen levels among tag treatment groups ($P = 0.584$). ELISA values for laboratory fish that survived 90 d ranged from 0.040 to 0.240 (with two outliers at 0.308 and 0.419). Since ELISA values for all but a few fish were considered low, no analysis was conducted to evaluate differences among treatment groups.

14. Evidence from CWTs collected from laboratory fish indicated that no single hatchery group contributed fish to our study that were obviously compromised in numbers sufficient to bias our results.

Overall, results of research conducted in 2007 indicated that there were tagging or handling effects associated with the use of acoustic tag technology in juvenile Chinook salmon. These effects were manifested as higher mortality in acoustic-tagged than in PIT-tagged yearling Chinook of both life history types. The magnitude of these effects differed between life history types, as well as between serial release groups, as did the distance from release whereby differences between treatment groups became apparent.

Differences in detection probability, as well as trends toward slower travel times in acoustic-tagged fish, were observed in both life history types, indicating possible behavioral differences between tag treatments. In the laboratory, subtle differences in PIT tag loss between the two tag groups (yearling and subyearling Chinook), were also observed, and in some instances were of a direction and magnitude to explain the observed differences in detection probability. Overall, the tag effects observed were more prominent in subyearling than in yearling Chinook salmon , both for active migrants and laboratory fish.

There is considerable potential cost associated with a type II error in this evaluation, that is, with a failure to recognize a real difference between tag effects. This is true in terms of both funding for expensive new technology and in potential harm to a living marine resource that could result from underestimating the effects of a new tag. For this reason, we noted not only differences that were significant at $\alpha = 0.05$, but also those that were significant at the 0.100 level.

Similar to Skalski et al. (2003; 2005) and Hockersmith et al. (2003), we did not find significant differences in mean survival ($\alpha = 0.05$) for 10 paired releases of AT and PIT-tagged yearling Chinook groups over a moderate distance from release (~225 km or median travel time of ~8 d). However at $\alpha = 0.10$, we saw higher survival in AT than PIT-tagged fish approximately 106 km (~5 d) from release, and higher survival in PIT than AT at approximately 225 km (~8 d). Importantly, we also observed considerable variation in relative survival among the 10 paired release groups at McNary Dam (AT/PIT ranged from 0.81 to 1.00). Environmental data indicated that these release groups had been subjected to different environmental conditions throughout spring, particularly with regard to Snake River flow. Although we were unable to find a direct connection between environmental conditions and survival, the survival/flow patterns we observed indicate that a connection is likely. Thus we recommend further analyses of these relationships.

Because flow and travel time are generally correlated, we suspect that potential differences in survival may have been related more to the time-period when replicates were in the river than to the distance travelled. As such, effects on survival may be better predicted by some combination of time in river, and distance rather than by distance alone. For this reason, we cannot yet make definitive predictions or conclusions regarding the exact conditions under which AT tagging will have virtually no effect in yearling Chinook salmon. Furthermore, estimates of mean detection probability for the 10 yearling Chinook release groups were significantly different (albeit by a small margin) at the first downstream detection site in 2007 (~60 km/median travel time ~4 d). This suggested that a behavioral difference may exist that was manifested prior to the observed differences in survival.

Mean rates of survival, detection probability, and travel time were different between the 10 paired releases of AT and PIT tagged subyearling Chinook. These differences were significant at Little Goose Dam, which was first downstream detection site located 60 km from release (median travel time 5.2 d for AT and 3.9 d for PIT). Trends in the data also suggested that the tag effect observed in subyearling Chinook may have been influenced by additional variables such as flow, temperature, and/or size of fish at tagging, rather than by distance traveled alone. As such, similar to the yearlings, the appropriate use of contemporary acoustic tags in subyearling Chinook may be better predicted through some combination of these variables than by distance alone.

Possible etiologies behind the effects observed in acoustic-tagged fish relative to PIT-tagged fish appeared to be consistent between yearling and subyearling Chinook salmon. Compared to PIT tags, acoustic tags were more likely to elicit an inflammatory response both within the peritoneal cavity and at the incision site. This inflammatory response may have placed a higher metabolic demand on the AT group relative to the PIT group. There is some evidence based on gross necropsy that PIT groups were more fit than AT groups when they reached downstream recapture locations. However, the differences in nutritional indicators from gross necropsy were primarily based on trends in the data rather than statistical differences between tag treatments, and these trends were not supported by results from the histological examinations. Although copious bacteria or fungi were not apparent on histological exam, an infectious cause for the observed inflammation cannot be ruled out. Infection would have compromised AT fish relative to PIT-tagged fish directly. Differences in performance between AT and PIT-tagged fish may also have been due to reduced fitness in AT fish due to mechanical appetite suppression, or simply to the additional tag burden experienced by this group.

Results from gross necropsy also showed that adverse effects may be related to the surgical tagging procedure, indicating slower healing of the AT incision compared to the PIT-tag injection wound. These effects were likely amplified in subyearling relative to yearling Chinook due to their smaller size, more metabolically active status, and the less favorable river conditions experienced by migrating subyearlings.

Subyearling Chinook salmon are known to feed at higher rates during downstream migration than yearling fish (Conner et al. 2004), and in general, their flesh appears more prone to swelling and tearing. Fish that are actively feeding might place more pressure on an incision than those that are fasting or feeding less rigorously, and pressure on the incision may interfere with healing or lead to full-blown wound dehiscence. Furthermore, subyearling Chinook are collected and tagged when the river is becoming warmer and fish are more biologically active. These factors made it more likely for subyearling fish to drop or expel tags, contract infections at the incision site, or succumb to other stressors incurred during handling than yearling fish.

Initial results of our study suggest that both yearling and subyearling Chinook with acoustic implants may experience lower survival, and may behave differently and/or be detected differently than PIT-tagged fish at variable distances from release, depending on travel conditions. In 2008, tagging experiments, including both releases to the river and long-term holding of yearling Chinook, were repeated. These later experiments were conducted, at least in part, amid more normal river flow conditions. In addition, long-term holding experiments using subyearling Chinook were conducted under cooler water temperatures compared to 2007.

In 2008, we also photographed migrating acoustic-tagged fish prior to release and laboratory holding fish both before and after treatment. These photographs may help to identify external physical abnormalities, which in turn may provide information on how fish condition at the time of tagging (e.g., percentage of descaling) influences survival. We included an additional reference group in both the yearling and subyearling long-term holding experiments to represent fish subjected to the surgical process (incision and suture placement) but not the additional burden of an acoustic tag. An additional experimental group was included in the subyearling laboratory holding study to identify whether potential dip treatments, such as hydrogen peroxide, promoted surgical-tag incision healing. These subyearling fish are being monitored and their healing photographed weekly.

Analyses of additional data collected in 2008 and multivariate analyses of 2 years of data will aid in the interpretation of comparisons between AT and PIT-tagged fish, given the dissimilar environmental conditions observed between years. These analyses may provide more definitive conclusions and allow more specific recommendations regarding the effects of the contemporary acoustic tag and its implantation procedure on juvenile Chinook salmon. Ideally, we will be able to identify groups of fish by fork length, length of river reach, time in river, or environmental conditions (e.g., temperature or flow) so that these critical variables can be considered in estimates of survival for acoustic-tagged fish.

Finally, many test results reported herein verged on being significantly different between tag treatments. Therefore for a more complete evaluation of tag effects, sample size will need to be increased to increase the power of the tests to discern whether differences exist at the $\alpha = 0.05$ level. Interestingly, we also found evidence of abnormalities in PIT-tagged fish during histological examinations that warrant further investigation with respect to the potential effects of PIT tags on adult return rates.

ACKNOWLEDGEMENTS

The collaborative effort of multiple agencies and people led to successful completion of this work, and we express gratitude to all who contributed. We especially thank M. Brad Eppard for his insight and assistance coordinating research activities and the Portland District U.S. Army Corps of Engineers for funding this research. For help in the field, we thank PNNL researchers and technicians Kathleen Carter, Brian Bellgraph, Jennifer Panther, Matt Bleich, Abby Welch, John Stephenson, James Hughes, Shon Zimmerman, Nathan Phillips, Katie Ovink, Jen Monroe, Carmina Arimescu, Scott Titzler, Corey Duberstein and Katie Murray. Field help was also provided by NOAA Fisheries research staff Jason Everett, Neil Paasch, Lynn McComas, and Ken McIntyre.

For their assistance in the field and laboratory, we express much gratitude to Pacific States Marine Fisheries Commission researchers and technicians Larry Basham, Lila Charlton, Chris Eaton, Ethan Ellsworth, Cheryl Engle, and Laura Leighton. We express our appreciation to Scott Davidson, and the entire NOAA Pasco Shop for providing critical logistics for tagging and subsampling, without which this work would not have been possible. We also thank Doug Marsh of NOAA Fisheries for his invaluable assistance and guidance. We thank his Pacific States Marine Fisheries crew for collecting and sorting fish and for tagging reference fish for this study. To Brenda James, Paul James, Andrew Puls, Kara Prather, and Keith Pitts of Cascade Aquatics, thanks for activating and delivering the acoustic tags. Thank also to Peter Kuechle of Advanced Telemetry Systems for sharing his expertise.

Thanks to Mike Halter of USACE and his staff at Lower Granite Dam for helping to coordinate this work and collect fish. For their assistance and advice, we thank Fred Mensik, Doug Ross, and Shawn Rapp of the Washington Department of Fish and Wildlife Smolt Monitoring Program at Lower Granite Dam. We express appreciation to Dave Marvin of the Pacific States Marine Fisheries Commission for making possible our subsampling using the SbyC system. Thanks also to USACE project biologists Brad Eby (McNary Dam), Ben Hausmann (Bonneville Dam), and Jonathon Rerecich (Bonneville Dam), and Dean Ballanger (SMP Bonnville Dam) for assistance in coordinating the SbyC and laboratory work conducted at these facilities.

We thank John Skalski and Rebecca Buchanan of the University of Washington for lending their statistical expertise for the analysis of both PIT- and acoustic-tag detection data. We thank USACE project biologist Greg Moody (Little Goose Dam) and ODFW biologists Ruth Shearer and Annie Dowdy for their attention and support at Little Goose Dam. We thank Kathleen Moyer with ODFW for providing predation information. Thanks also to Dave Hurson and John Bailey of the Walla Walla District USACE.

We also thank Kenneth Ham, Dennis Dauble, Gayle Dirkes, Kathy Lavender, David Geist, Julie Hughes, Craig Allwardt, and R. Eric Robinson of PNNL. We thank Tom Ruhle, Kinsey Frick, and John Ferguson of NOAA Fisheries for their council and administrative support. Finally, we express our gratitude to JoAnne Butzerin for her insight and assistance in editing this report.

REFERENCES

Absolon, R. F., M. B. Eppard, B. P. Sandford, G. A. Axel, E. E. Hockersmith, and J. W. Ferguson. 2003. Effects of turbines operating at two different discharge levels on survival and condition of yearling Chinook salmon at McNary Dam, 2002. Report to U.S. Army Corps of Engineers, Contract W68SBV20655422. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Adams, N. S., D. W. Rondorf, and E. E. Kofoot. 1996. Migrational characteristics of juvenile spring Chinook salmon and steelhead in the forebay of Lower Granite Dam relative to the 1996 surface bypass collector tests. Report to the U.S. Army Corps of Engineers, Contract E-86930151, Walla Walla, WA.

Adams, N. S., D. W. Rondorf, and E. E. Kofoot. 1997. Migrational characteristics of juvenile spring Chinook salmon and steelhead in the forebay of Lower Granite Dam relative to the 1997 surface bypass collector tests. Report to the U.S. Army Corps of Engineers, Contract E-86930151, Walla Walla, WA.

Adams, N. S., D. W. Rondorf, S. D. Evans, J. E. Kelly, and R. W. Perry. 1998. Effects of surgically and gastrically implanted radio transmitters on swimming performance and predator avoidance of juvenile Chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 55:781-787.

Anglea, S. M., D. R. Geist, R. S. Brown, K. A. Deters, and R. D. McDonald. 2004. Effects of Acoustic Transmitters on Swimming Performance and Predator Avoidance of Juvenile Chinook Salmon. North American Journal of Fisheries Management 24:162-170.

Anglea, S., T. Poe, and A. Giorgi. 2001. Synthesis of radio telemetry, hydroacoustic, and survival studies of juvenile salmon at John Day Dam (1980-2000). Report to U.S. Army Corps of Engineers, Portland, Oregon.

Axel, G. A., E. E. Hockersmith, M. B. Eppard, B. P. Sandford, S. G. Smith, and D. B. Dey. 2003. Passage behavior and survival of hatchery yearling Chinook salmon passing Ice Harbor and McNary Dams during a low flow year, 2001. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Axel, G. A., E. E. Hockersmith, M. B. Eppard, and B. P. Sandford. 2004a. Passage and survival of hatchery yearling Chinook salmon at McNary Dam, 2002. Report to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Axel, G. A., E. E. Hockersmith, M. B. Eppard, and B. P. Sandford. 2004b. Passage and survival of hatchery yearling Chinook salmon at McNary Dam, 2003. Report to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Berggren, T. J., and M. J. Filardo. 1993. An analysis of variables influencing the migration of juvenile salmonids in the Columbia River basin. North American Journal of Fisheries Management 13:48-63.

Bridger, C. J., and R. K. Booth. 2003. The effects of biotelemetry transmitter presence and attachment procedures on fish physiology and behavior. Reviews in Fisheries Science 11:13-34.

Brown, R. S., S. J. Cooke, W. G. Anderson, and R. S. McKinley. 1999. Evidence to challenge the "2% rule" for biotelemetry. North American Journal of Fisheries Management 19:867-871.

Brown, R. S., D. R. Geist, K. A. Deters, and A. Grassell. 2006. Effects of surgically implanted acoustic transmitters >2% of body mass on the swimming performance, survival and growth of juvenile sockeye and Chinook salmon. Journal of Fish Biology 69:1626-1638.

Brown, R. S., K. M. Carter, K. A. Deters, D. R. Geist, G. A. McMichael, C. A. McKinstry, and R. Elson. 2007a. Evaluation of growth, survival, tag expulsion, and tissue reaction in acoustic-tagged juvenile salmonids. Pages 31-70 *in* E. E. Hockersmith, R. S. Brown, and T. L. Liedtke, editors. Comparative performance of acoustic-tagged and passive integrated transponder-tagged juvenile salmonids. Report of the National Marine Fisheries Service, Pacific Northwest National Laboratory, and U.S. Geological Survey to the U.S. Army Corps of Engineers, Portland District.

Brown, R. S., K. M. Carter, K. A. Deters, and C. A. McKinstry. 2007b. Determination of a minimum fish size for implantation with a Juvenile Salmonid Acoustic Telemetry System (JSATS) tag. Pages 71-81 *in* E. E. Hockersmith, R. S. Brown, and T. L. Liedtke, editors. Comparative performance of acoustic-tagged and passive integrated transponder-tagged juvenile salmonids. Report of the National Marine Fisheries Service, Pacific Northwest National Laboratory, and U.S. Geological Survey to the U.S. Army Corps of Engineers, Portland District.

Bunnell, D. B. and Isely, J. J. 1999. Influence of Temperature on Mortality and Retention of Simulated Transmitters in Rainbow Trout. North American Journal of Fisheries Management 19:152-154.

Chisholm, I. M. and Hubert, W. A. 1985. Expulsion of Dummy Transmitters by Rainbow Trout. Transactions of the American Fisheries Society 114:766-767.

Connor, W. P., Smith, S. G., Andersen, T., Bradbury, S. M., Burum, D. C., Hockersmith, E. E., Schuck, M. L., Mendel, G. W., and Bugert, R. M. 2004. Postrelease Performance of Hatchery Yearling and Subyearling Fall Chinook Salmon Released into the Snake River. North American Journal of Fisheries management 24: 545-560.

Conner, W. P., J. G. Sneva, K. F. Tiffan, R. K. Steinhorst, D. Ross. 2005. Two alternative juvenile life history types for fall Chinook salmon in the Snake River Basin. Transactions of the American Fisheries Society 134:291-304.

Cormack, R. M. 1964. Estimates of survival from sightings of marked animals. Biometrika 51:429-438.

Eppard, M. B., G. A. Axel, B. P. Sandford, and G. M. Matthews. 1998. Ice Harbor Dam spill efficiency determined by radio telemetry, 1997. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Eppard, M. B. , E. E. Hockersmith, G. A. Axel, and B. P. Sandford. 2002. Spillway survival for hatchery yearling and subyearling Chinook salmon passing Ice Harbor Dam, 2000. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Eppard, M. B., B. P. Sandford, E. E. Hockersmith, G. A. Axel, and D. B. Dey. 2005a. Spillway passage survival of hatchery yearling and subyearling Chinook salmon at Ice Harbor Dam, 2002. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Eppard, M. B., B. P. Sandford, E. E. Hockersmith, G. A. Axel, and D. B. Dey. 2005b. Spillway passage survival of hatchery yearling Chinook salmon at Ice Harbor Dam, 2003. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Gessel, M. H., J. G. Williams, D. A. Brege, R. F. Krcma, D.R. Chambers. 1991. Juvenile salmonid guidance at the Bonneveille Dam Second Powerhouse, Columbia River, 1983-1989. North American Journal of Fisheries Management 11: 400-412.

Giorgi, A. E., G. A. Swan, W. S. Zaugg, T. C. Coley, T. Y. Barila. 1988. Susceptibility of Chinook salmon smolts to bypass systems at hydroelectric dams. North American Journal of Fisheries Management 8: 25-29.

Giorgi, A. E., T. W. Hillman, J. R. Stevenson, S. G. Hays, and C. M. Peven. 1997. Factors that influence the downstream migration rates of juvenile salmon and steelhead through the hydroelectric system in the mid-Columbia River basin. North American Journal of Fisheries Management 17:268-282.

Goede, R. W., and B. A. Barton. 1990. Organismic indices and an autopsy-based assessment as indicators of health and condition of fish. American Fisheries Society Symposium 8:93-108.

Greenstreet, S. P. R., and R. I. G. Morgan. 1989. The effect of ultrasonic tags on the growth rates of Atlantic salmon *Salmo salar* L., parr of varying size just prior to smolting. Journal of Fish Biology 35:301-309.

Hensleigh, J. E., H. C. Hansel, R. S. Shively, R. E. Wierenga, J. M. Hardiman, R. H. Wertheimer, G. S. Holmberg, T. L. Martinelli, B. D. Leidtke, R. E. Wardell, and T. P. Poe. 1997. Movement and behavior of radio-tagged yearling Chinook salmon and steelhead in John Day, the Dalles, and Bonneville dam forebays. Preliminary report to the U.S. Army Corps of Engineers, Portland, OR.

Hockersmith, E. E., G. A. Axel, M. B. Eppard, D. A. Ogden, and B. P. Sandford. 2005. Passage behavior and survival for hatchery yearling Chinook salmon at Lower Monumental Dam, 2004. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Hockersmith, E. E., R. S. Brown, and T. L. Liedtke. 2007a. Comparative performance of acoustic-tagged and passive integrated transponder-tagged juvenile salmonids. Report of the National Marine Fisheries Service, Pacific Northwest National Laboratory, and U.S. Geological Survey to the U.S. Army Corps of Engineers, Portland District. Available at www.nwfsc.noaa.gov/publications/searchdoc.cfm (September 2009).

Hockersmith, E. E., R. S. Brown, R. L. McComas, B. J. Bellgraph, B. P. Sandford, J. A.Vucelick, B. Ryan, and G A. McMichael. 2007b. Field evaluation of acoustic telemetry tags in juvenile salmonids. Pages 1-82 *in* E. E. Hockersmith, R. S. Brown, and T. L. Liedtke, editors. Comparative performance of acoustic-tagged and passive integrated transponder-tagged juvenile salmonids. Report of the National Marine Fisheries Service, Pacific Northwest National Laboratory, and U.S. Geological Survey to the U.S. Army Corps of Engineers, Portland District.

Hockersmith, E. E., W. D. Muir, S. G. Smith, B. P. Sandford, R. W. Perry, N. S. Adams, and D. W. Rondorf. 2003. Comparison of migration rate and survival between radio-tagged and PIT-tagged migrant yearling chinook salmon in the Snake and Columbia rivers. North American Journal of Fisheries Management 23:404-413.

Hockersmith, E. E., S. G. Smith, W. D. Muir, B. P. Sandford, J. G. Williams, and J. R. Skalski. 1999. Survival estimates for the passage of juvenile salmonids through Snake River dams and reservoirs, 1997. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Hollander, M. and I. Wolfe. 1973. Nonparametric Statistical Methods. 503 p. Wiley and Sons, New York.

Jepsen, N., A. Koed, E. B. Thorstad, and E. Baras. 2002. Surgical implantation of telemetry transmitters in fish: how much have we learned? Hydrobiologia 483:239-248.

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration–stochastic model. Biometrika 52:225-247.

Kaseloo, P. A., A. H. Weatherley, J. Lotimer, and M. D. Farina. 1992. A biotelemetry system recording fish activity. Journal of Fish Biology 40:165-179.

Knights, B. C., and B. A. Lasee. 1996. Effects of implanted transmitters on adult bluegills at two temperatures. Transactions of the American Fisheries Society 125:440-449.

Lacroix, G. L., D. Knox, and P. McCurdy. 2004. Effects of implanted dummy acoustic transmitters on juvenile Atlantic salmon. Transactions of the American Fisheries Society 133:211-220.

Liedtke, T. L., L. P. Gee, M. G. Mesa, J. W. Beeman, D. G. Elliot, and C. M. Conway. 2007. Evaluation of predator avoidance ability, tag loss, and tissue response of acoustic-tagged juvenile salmonids. Pages 83-111 *in* E. E. Hockersmith, R. S. Brown, and T. L. Liedtke, editors. Comparative performance of acoustic-tagged and passive integrated transponder-tagged juvenile salmonids. Report of the National Marine Fisheries Service, Pacific Northwest National Laboratory, and U.S. Geological Survey to the U.S. Army Corps of Engineers, Portland District.

Lucas, M.C. 1989. Effects of implanted dummy transmitters on mortality, growth and tissue reaction in rainbow trout, *Salmo gairdneri* Richardson. Journal of Fish Biology 35:577-587.

Luna, L. G. 1968. Manual of histological staining methods of the Armed Forces Institute of Pathology. McGraw-Hill, New York.

Marsh, D. M., J. R. Harmon, , K. W. McIntyre, K. L. Thomas, N. N. Paasch, B. P. Sandford, D. J. Kamikawa, and G. M. Matthews. 1996. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 1995. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla, Walla, Washington.

Marsh, D. M., J. R. Harmon, N. N. Paasch, K. L. Thomas, K. W. McIntyre, B. P. Sandford, and G. M. Matthews. 2001. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 2000. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla, Walla, Washington.

Marty, G. D., and R. C. Summerfelt. 1986. Pathways and mechanisms for expulsion of surgically implanted dummy transmitters from channel catfish. Transactions of the American Fisheries Society 115:577-589.

Marty, G. D. and Summerfelt, R. C. 1990. Wound Healing in Channel Catfish by Epithelialization and Contraction of Granulation Tissue. Transactions of the American Fisheries Society 119:145-150.

Maynard, D. J., D. A. Frost, F. W. Waknitz, and E. F. Prentice. 1996. Vulnerability of marked age-0 steelhead to a visual predator. Transactions of the American Fisheries Society 125:330-333.

McComas, R. L., D. Frost, S. G. Smith, J. W. Ferguson, T. Carlson, and T. Aboellail. 2005. A study to estimate juvenile salmonid survival through the Columbia River estuary using acoustic tags, 2002. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Portland District.

Moore, A., I. C. Russell, and E. C. E. Potter. 1990. The effects of intraperitoneally implanted dummy acoustic transmitters on the behaviour and physiology of juvenile Atlantic salmon, Salmo salar L. Journal of Fish Biology 37:713-721.

Murchie, K. J., S. J. Cooke, and J. F. Schreer. 2004. Effects of radio-transmitter antenna length on swimming performance of juvenile rainbow trout. Ecology of Freshwater Fish 13:312-316.

Noga, Edward J. 1996. Fish Disease–Diagnosis and Treatment. Mosby Year Book Inc., St. Louis, Missouri.

Ogden, D. A., E. E. Hockersmith, M. B. Eppard, G. A. Axel, and B. P. Sandford. 2005. Passage behavior and survival for river-run subyearling Chinook salmon at Ice Harbor Dam, 2004. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla, Walla, Washington.

PSMFC (Pacific States Marine Fisheries Commission). 1996. Columbia Basin PIT tag information system (PTAGIS). Pacific States Marine Fisheries Commission, Gladstone, Oregon. Available at www.ptagis.org/ptagis/index.jsp (December 2008).

Pascho, R. J. and D. Mulcahy. 1987. Enzyme-linked immunosorbent assay for a soluble antigen of *Renibacterium salmoninarum*, the causative agent of salmonid bacterial kidney disease. Canadian Journal of Fisheries and Aquatic Sciences 44:183-191.

Pascho, R.J., D.G. Elliott and J.M. Streufert. 1991. Brood stock segregation of spring Chinook salmon *Onchorhynchus tshawytscha* by use of the enzyme-linked immunosorbent assay (ELISA) and the fluorescent antibody technique (FAT) affects the prevalence and levels of *Renibacterium salmoninarum* infection in progeny. Diseases of Aquatic Organisms 12:25-40.

Perry, R. W., N. S. Adams, D. W. Rondorf. 2001. Buoyancy compensation of juvenile Chinook salmon implanted with two different size dummy transmitters. Transactions of the American Fisheries Society 130:46-52.

Ploskey, G., T. Poe, A. Giorgi, and G. Johnson. 2001. Synthesis of radio telemetry, hydroacoustic, and survival studies of juvenile salmon at the Dalles Dam (1982-2000). Report to U.S. Army Corps of Engineers, Portland, Oregon.

Prentice, E. F., T. A. Flagg, and S. C. McCutcheon. 1990a. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. American Fisheries Society Symposium 7:317-322.

Prentice, E. F., T. A. Flagg, C. S. McCutcheon, and D. F. Brastow. 1990b. PIT-tag monitoring systems for hydroelectric dams and fish hatcheries. American Fisheries Society Symposium 7:323-334.

Roberts, R. J., A. MacQueen, W. M. Shearer, and H. Young. 1973. The histopathology of salmon tagging III. Secondary infections associated with tagging. Journal of Fish Biology 5:621-623.

Seber, G. A. H. 1965. A note on the multiple recapture census. Biometrika 52:249-259.

Skalski, J. R., R. L. Townsend, A.E. Giorgi, and J. R. Stevenson. 1998. The design and analysis of salmonid tagging studies in the Columbia River Basin. Volume XI: Recommendations on the design and analysis of radiotelemetry studies of salmonid smolts to estimate survival and passage efficiencies. Draft report to Bonneville Power Administration, Project 89-107.

Skalski, J. R., R. L. Townsend, T. W. Steig, J. W. Horchik, G. W. Tritt, and A. Grassell. 2003. Estimation of survival of yearling chinook salmon smolts the Rock Island Dam, pool, and project in 2002 using acoustic and PIT-tag release-recapture methods. Report by Columbia Basin Research to Chelan Co. PUD, Wenatchee, WA, 87 pp.

Skalski, J. R., R. L. Townsend, T. W. Steig, P. A. Nealson, K. K. Kumagai, and A. Grassell. 2005. Estimation of survival of yearling and subyearling Chinook, and sockeye salmon smolts, and steelhead at Rocky Reach and Rock Island Projects in 2004 using acoustic and PIT-tag release-recapture methods. Report to the Public Utility District No. 1 of Chelan County, Wenatchee, Washington.

Smith, S. G., W. D. Muir, E. E. Hockersmith, R. W. Zabel, R. J. Graves, C. V. Ross, W. P. Connor, and B. D. Arnsberg. 2003. Influence of river conditions on survival and travel time of Snake River subyearling fall Chinook salmon. North American Journal of Fisheries Management 23:939-961.

Smith, S. G., J. R. Skalski, W. Sclechte, A. Hoffmann, and V. Cassen. 1994. Statistical survival analysis of fish and wildlife tagging studies. SURPH. 1. Manual developed by the Center for Quantitative Science, School of Fisheries, University of Washington for the Bonneville Power Administration. Portland, Oregon.

Snedecor, G. W., and W. G. Cochran. 1980. Statistical methods. Iowa State College Press, Ames, Iowa.

Steig, T. W., J. R. Skalski, and B. H. Ransom. 2004. Comparison of acoustic and PIT tagged juvenile chinook, steelhead and sockeye salmon (Oncorhynchus spp.) passing dams on the Columbia River, USA. Pages 275-286 *in* M. T. Spedicato, G. Lembo, and G. Marmulla, editors. Aquatic telemetry-advances and applications, Proceedings of the Fifth Conference on Fish Telemetry in Europe, Ustica, Italy, 9-13 June 2003. Food and Agriculture Organization Special Publication, Rome.

Stein, C., D. Marvin, J. Tenney, and N. Gruman. 2004. 2004 PIT tag specification document. Report to the PIT Tag Steering Committee. 152 p.

Summerfelt, R. C., and L. S. Smith. 1990. Anesthesia, surgery, and related techniques. Pages 213-263 *in* C. B. Schreck and P. B. Moyle, editors. Methods for fish biology. American Fisheries Society, Bethesda, Maryland.

Tabor, R. A., R. S. Shively, and T. P. Poe. 1993. Predation on juvenile salmonids by smallmouth bass and northern squawfish in the Columbia River near Richland, Washington. North American Journal of Fisheries Management 13:831-838.

URF (Use of Fishes in Research) Committee. 2004. Guidelines for the use of fishes in research. American Fisheries Society, Bethesda, Maryland.

Vigg, S., and C. C. Burley. 1991. Temperature-dependent maximum daily consumption of juvenile salmonids by northern squawfish (*Ptychocheilus oregonensis*) from the Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 48:2491-2498.

Walsh, M. G., A. K. Bjorgo, and J. J. Isely. 2000. Effects of implantation method and temperature on mortality and loss of simulated transmitters in hybrid striped bass. Transactions of the American Fisheries Society 129:539-544.

Winter, J. D. 1996. Advances in underwater biotelemetry. Pages 555-590 *in* Murphy, B.R. and D.W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

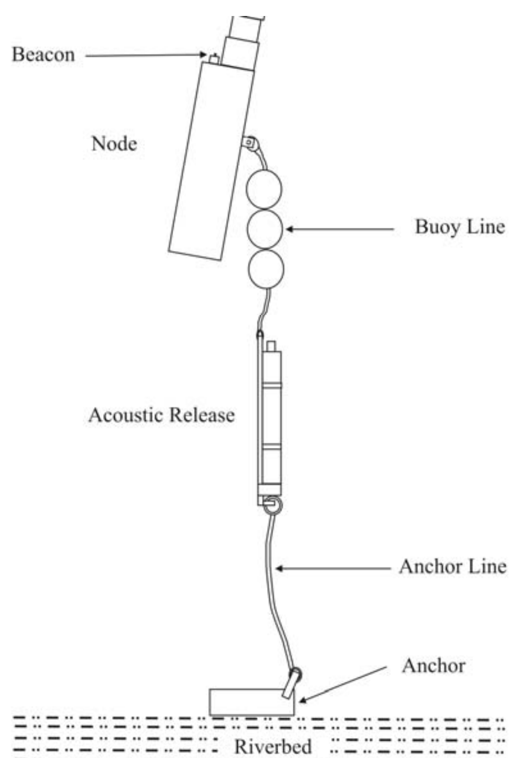
APPENDIX A

Acoustic Receiver Arrays

Appendix Table A1. Locations of acoustic receiver arrays used for passage and survival estimates in comparison of the JSATS and PIT tag, 2007.

Acoustic receiver arrays		
Abbreviation	Site description	Location (rkm)
IRR1	Irrigon primary array	452
BON0	Bonneville egress, 14 km ds of Bonneville Dam	225.2
BON1	Bonneville primary, Sand Island	210.4
BON2	Bonneville secondary, Reed Island	204.0
BON3	Bonneville tertiary, Lady Island	199.1
KLM1	Kalama primary, Cottonwood Island	112.6
KLM2	Kalama secondary, Cottonwood Island	110.7
EIS1	Estuary islands primary, Oak Pt	86.2
EIS2	Estuary islands secondary, ds from Oak Pt	83.6
EIS3	Estuary islands tertiary, Tenasillahe Island	58.4
EST1	Estuary primary, W. Sand Island	8.3
EST2	Estuary secondary, between N and S Jetties	2.8

Autonomous receiving nodes (Model N201, Sonic Concepts, Inc.) were composed of electronics, on-board power, data storage (CF card), and a hydrophone housed in a 1.2-m long by 15-cm diameter PVC tube. Nodes were deployed to detect and record the presence of passing fish bearing JSATS acoustic transmitters. Each autonomous node consisted of a hydrophone, battery compartment, beacon transmitter, buoy line, acoustic release (Model 111, InterOcean Systems Inc.), anchor line, and anchor (Appendix Figure A1). Beacons emitted a signal every 15 seconds, which confirmed that hydrophones were working properly. Depending on water depth, each acoustic release was shackled to a 35-kg anchor with either a 1.5- or 3.6-m long shock-corded mooring (Appendix Figure A1).



Appendix Figure A1. Diagram of the orientation of an autonomous node and rigging as it was deployed in the river.

Each receiver underwent a rigorous acceptance testing protocol prior to delivery from the manufacturer and deployment in the field. A gross examination was completed to ensure that all parts were present and properly labeled. The nodes were then activated, and basic function was evaluated including proper calibration of pressure and temperature sensors and the system clock, and that the node was able to properly receive, decode, and store acoustic signals to the CF card. Node performance was measured and the housing was tested for leaks. This was done in a small, portable tank lined with anechoic material, using a signal generator and attenuator to simulate range. Each node was placed in the tank approximately 6 feet from the signal generator element. An attenuation curve was created by calculating the percentage of transmissions that were correctly detected and decoded at each of 6 signal levels (i.e., -40, -50, -55, -60, -65, and -70 dB). Acceptance criteria required detection efficiency of 50% or higher at the -40, -50, and -55 dB levels. Nodes that failed any of the test protocols were returned to the manufacturer for repair or replacement and were retested prior to use in the field.

Nodes were deployed in a line perpendicular to the river channel and placed well within their maximum detection range of 300 m to provide detection coverage across the full width of the river at each location.

Receivers were recovered and serviced bi-weekly throughout the study period. To recover each node, the boat was situated close to the waypoint of the node which was displayed on a laptop computer using Fugawi Marine ENC (Northport Systems Inc.) map software. A command unit and transducer (Model 1100E, InterOcean Systems Inc.) were used to activate the acoustic release. Upon receiving the signal from the command unit, the acoustic release opened and released the ring on the anchor line (Appendix Figure A1), which allowed the node and release to float to the surface. The node and release were recovered from the river and the data file was cursorily examined to determine if the node had been collecting data properly. The node was then connected to a laptop computer and the node clock synchronized with GPS.

Data collection was observed in real time using the beacon transmitter on the node body to confirm at least 3 consecutive detections. The acoustic release was re-armed using two hand-held magnets to activate the motor to close the link to a new anchor line attached to a new anchor. Using GPS and Fugawi, the boat was positioned as close to the previous deployment point as possible, then the re-activated node was lowered to the bottom using a rope fed through the anchor handle to control its decent. As nodes were deployed a new waypoint was created and the time, depth, and the latitude and longitude were recorded.

Data collected by the autonomous nodes were recorded as a single text file on CF cards. Physical data (i.e., date, time, pressure, water temperature, tilt, and battery voltage) were written to file every 15 seconds. Valid acoustic transmitter detection data were recorded as they were received. Detection data included individual transmitter code, time stamp, receive signal strength indicator, and a calculated measure of background noise (i.e., RxThreshold). Each data file was transferred to a laptop computer following servicing or retrieval events.

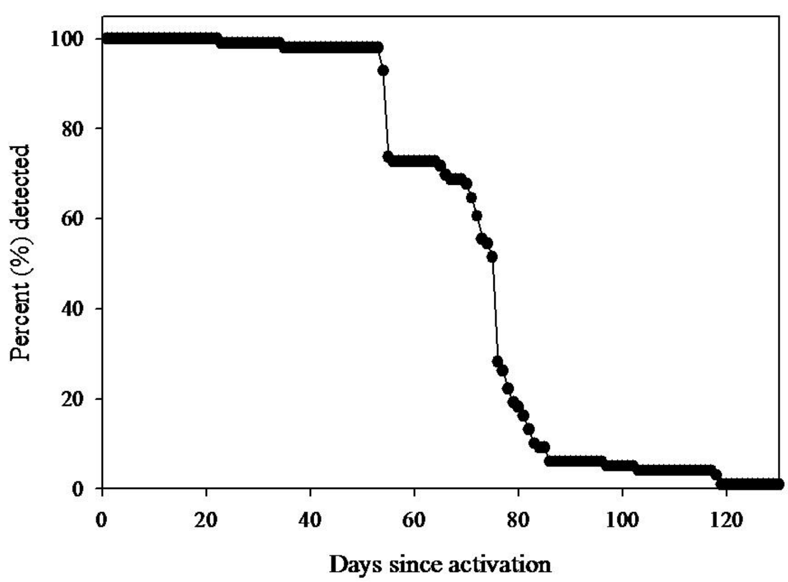
Data files from all nodes were coded with the node location and stored in a database developed specifically for storing and processing acoustic telemetry data. To filter out false positives (i.e., detections of otherwise valid tag codes that were not in the set of codes implanted in fish), a post-processing program was implemented. This program was comprised of a sequence of steps that compared each transmitter detection to a list of transmitters that were released and then compared the detection date to the release date. Only detections from the list of released transmitters that were detected after they were released were retained for analysis. A minimum of 4 detections in 120 seconds was required, and only detection events with the correct time spacing were retained in the valid detection file. From the valid detection file, a detection history was created for each fish, which was used to estimate detection probability and survival.

APPENDIX B

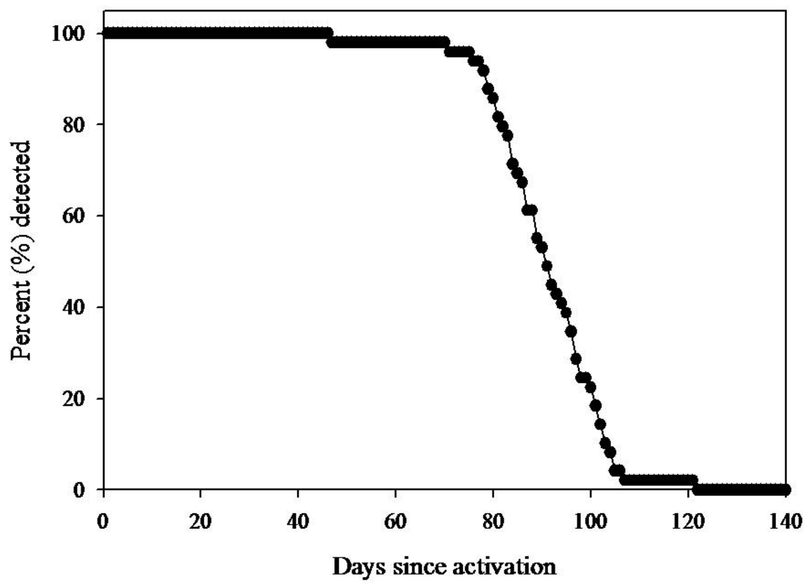
Transmitter Life

Fifty 2006 model and fifty 2007 model Sonic Concepts JSATS acoustic transmitters were withheld from implantation throughout the yearling migration season to estimate the life of transmitters implanted in AT fish. Transmitters were surgically implanted in hatchery-reared juvenile Chinook salmon at the Pacific Northwest National Laboratory (PNNL) aquatic research laboratory using procedures similar to those described above. Implanted fish were held indoors in 770 L flow-through tanks (1.29 m diameter × 0.59 m deep) with hydrophones from two Sonic Concepts Model N202 Portable Receiver Nodes suspended in the water column to detect acoustic transmitter signals. Transmitter detections were recorded to a compact flash (CF) card mounted in each portable node. Compact flash cards were downloaded and replaced weekly and node batteries were changed as needed. Implanted fish were held in the tanks until no signals were detected from any of the transmitters.

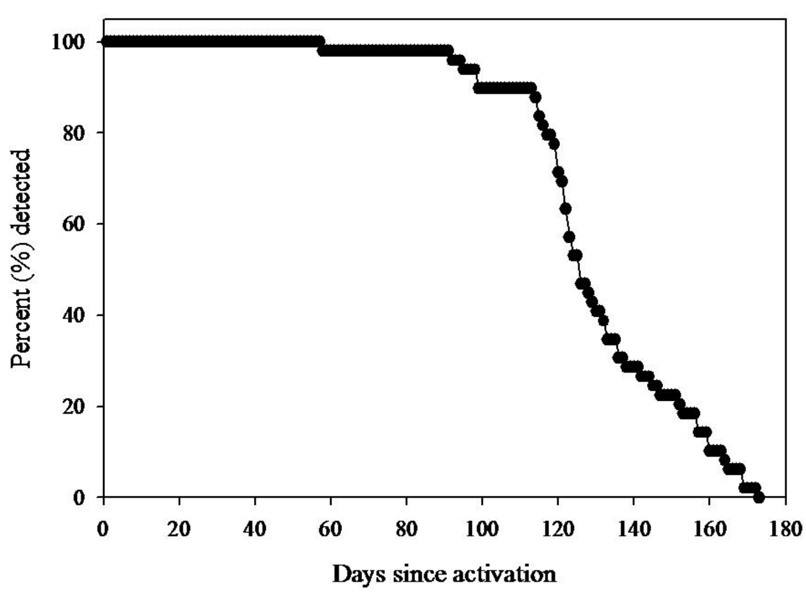
Fifty ATS acoustic transmitters were withheld from implantation throughout the subyearling migration season to estimate the life of transmitters implanted in AT test and AT pilot fish. Transmitters were surgically implanted in hatchery-reared juvenile Chinook salmon at the PNNL aquatic research laboratory and tag life was estimated using the same methods as described for estimating tag life of the Sonic Concepts acoustic transmitters implanted in yearling Chinook salmon.



Appendix Figure B1. Detections of 99 2006-model Sonic Concepts acoustic transmitters each day following activation. Data were used to estimate the life of transmitters implanted in river-run hatchery yearling Chinook salmon released into the tailrace of Lower Granite Dam, 2007.



Appendix Figure B2. Percent of forty-nine 2007 model Sonic Concepts acoustic transmitters detected in the laboratory each day following their activation. These data were used to estimate the life of transmitters implanted in river-run hatchery yearling Chinook salmon that were released into the tailrace of Lower Granite Dam, 2007.



Appendix Figure B3. Percent of 49 Advanced Telemetry Systems acoustic transmitters detected in the laboratory each day following their activation. These data were used to estimate the battery life of transmitters implanted in river-run hatchery subyearling Chinook salmon that were released into the tailrace of Lower Granite Dam, 2007.

APPENDIX C

Methods Used for Detection and Survival Probability Estimates Tag Effects Study: Statistical Approach

John Skalski and Rebecca Buchanan
Aquatic & Fishery Sciences
Center for Quantitative Science
University of Washington

Introduction

The effect of acoustic tagging on survival of migrating salmonid smolts was explored in a double-tagging study using PIT tags and acoustic tags. Two groups of smolts were collected at Lower Granite, tagged, and released to the Lower Granite tailrace. The control group was single-tagged with PIT tags alone, and the treatment group was double-tagged with both PIT tags and acoustic tags. The objective of the study was to estimate the relative survival (Δ) from Lower Granite to McNary of the double-tagged fish compared to the single-tagged fish, while accounting for tag failure or tag loss. For the following discussion, it is assumed that McNary is the first detection site, and detections at the second detection "site" are composed of all pooled detections downstream of McNary.

The Cormack-Jolly-Seber (CJS; Cormack 1964; Jolly 1965; Seber 1965) model is typically used to estimate survival of PIT-tagged salmonids between dams in the Columbia River. When detections of only a single type of tag (e.g., for single-tagged fish, or using only PIT-tag detections from double-tagged fish), the survival parameter estimated by the CJS model is the joint probability of fish survival and having an intact, operating tag. For this study, if the control fish (single-tagged) and treatment fish (double-tagged) have the same probability of tag loss, then the ratio of the CJS survival estimates to McNary for the two groups based solely on PIT-tag detections would be an unbiased estimator of Δ, the multiplicative effect of acoustic tags on survival. However, it is possible that the double-tagged fish experienced a different probability of PIT-tag loss than the single-tagged fish, because of differences in tagging methods: PIT tags were injected into single-tagged fish, and surgically implanted in double-tagged fish. Thus, the ratio of CJS survival estimates to McNary for the two groups, based only on PIT-tag data, will include tag loss probabilities for the two groups and will be biased for Δ, with an unknown bias.

The bias described above occurs because detections from only one type of tag (PIT tags) were used. However, fish in the treatment group have both PIT tags and acoustic tags. It is possible to use detection data from both types of tags in a two-reach CJS model to estimate the survival of treatment fish to McNary (or the first detection site) separately from tag loss. This can be done by jointly analyzing PIT-tag detections of treatment fish at McNary, and acoustic-tag detections of treatment fish at detection sites downstream of McNary in the CJS model. Under the assumption that loss or failure of PIT tags occurs independently of loss or failure of acoustic tags (either upstream or downstream of McNary), the CJS model yields an unbiased estimator of S_T, the survival of treatment (double-tagged) fish to McNary, regardless of tag loss or failure. This composite approach results in an estimator of Δ that has a better understood bias than the simple ratio of CJS survival estimates based on PIT-tag data alone. Additionally, this approach uses the available data more efficiently and so produces a more precise estimator than basing analysis on PIT-tag detections alone. Finally, this approach is attractive because it follows the original plan of using the downstream acoustic detections to augment the PIT-tag detections.

Methods

The analysis method is based on the following assumptions:

A1. All single-tagged fish have common survival probabilities downstream of Lower Granite, regardless of prior detection history.

A2. All single-tagged fish have common detection probabilities at McNary and at downstream detection sites, regardless of prior detection history.

A3. All double-tagged fish have common survival probabilities downstream of Lower Granite, regardless of prior detection history.

A4. All double-tagged fish with working PIT tags that reach McNary have a common probability of detection at McNary, regardless of prior detection history.

A5. All double-tagged fish with working acoustic tags that reach acoustic arrays downstream of McNary have a common probability of detection at those sites, regardless of prior PIT-tag detection history.

A6. The fate of each tagged fish is independent of the fate of all other tagged fish.

A7. All double-tagged fish have common probabilities of PIT-tag loss or failure between Lower Granite and McNary, and common probabilities of acoustic-tag loss or failure between Lower Granite and McNary.

A8. All double-tagged fish with working acoustic tags have common probabilities of acoustic-tag loss or failure downstream of McNary.

A9. Loss or failure of PIT tags occurs independently of loss or failure of acoustic tags.

Assumptions A1, A2, and A6 are the basic CJS assumptions used in analyzing PIT-tag detections from the control group. Assumptions A3-A6 are the basic CJS assumptions for the treatment fish, applied to both PIT-tag and acoustic-tag detection. Assumptions A7-A9 are necessary for parameterizing tag loss or failure for the treatment group, and for separating survival (or mortality) to McNary from tag loss.

Define the following parameters:

$S_C =$ Survival of control fish from release to McNary;

$S_T =$ Survival of treatment fish from release to McNary;

$S_{P(C)} =$ Probability that the PIT tag in a control fish neither fails nor is lost between release and McNary, i.e., "survival" of PIT tag for control fish;

$R_C =$ Number of fish released in the control group (single-tagged with PIT tags);

$R_T =$ Number of fish released in the treatment group (double-tagged with PIT tags and acoustic tags).

The ratio

$$\Delta = \frac{S_T}{S_C} \tag{0.1}$$

is the multiplicative effect of acoustic tags on survival from release at Lower Granite to McNary. If $\Delta < 1$, then acoustic tags lowered survival over the journey from Lower Granite to McNary.

As demonstrated in the Appendix, if detections from PIT tags only are used with the CJS two-reach model in the presence of tag loss, then the CJS parameter representing survival to the first detection site is actually the joint probability of fish survival and tag "survival" (Table A2 vs. Table A1). This means that for the control group, the CJS "survival" parameter $\left(S_{CJS(C)}\right)$ is actually the product of survival between release and the first site (McNary) and the probability of having a functioning PIT tag at McNary:

$$S_{CJS(C)} = S_C S_{P(C)}. \tag{0.2}$$

Without additional data, it is impossible to separately estimate S_C and $S_{P(C)}$.

Alternatively for the treatment group, if the CJS model is applied to detection histories composed of PIT-tag detections from the first site (McNary) and pooled acoustic-tag detections from downstream detection arrays (and if PIT-tag loss occurs independently of acoustic-tag loss), then the CJS "survival" parameter for treatment fish

$\left(S_{CJS(T)}\right)$ is simply survival of double-tagged fish from release to the first detection site (Table A3 vs. Table A1 in the Appendix):

$$S_{CJS(T)} = S_T. \tag{0.3}$$

The independent loss of PIT tags and acoustic tags allows separation of fish survival from PIT-tag survival in the first reach when both PIT-tag detections and acoustic-tag detections are used.

Define the following statistics:

$n_{1(C)}$ = number of control fish detected on PIT-tag detectors at McNary and on PIT-tag detectors downstream of McNary;

$n_{2(C)}$ = number of control fish detected on PIT-tag detectors at McNary, but not on PIT-tag detectors downstream of McNary;

$n_{3(C)}$ = number of control fish detected on PIT-tag detectors downstream of McNary, but not on PIT-tag detectors at McNary.

$n_{1(T)}$ = number of treatment fish detected on PIT-tag detectors at McNary and on acoustic arrays downstream of McNary;

$n_{2(T)}$ = number of treatment fish detected on PIT-tag detectors at McNary, but not on acoustic arrays downstream of McNary;

$n_{3(T)}$ = number of treatment fish detected on acoustic arrays downstream of McNary, but not on PIT-tag detectors at McNary.

The estimator for the CJS survival parameter for the control group is

$$\hat{S}_{CJS(C)} = \frac{\left(n_{1(C)} + n_{2(C)}\right)\left(n_{1(C)} + n_{3(C)}\right)}{R_C n_{1(C)}}, \tag{0.4}$$

with expected value

$$E\left(\hat{S}_{CJS(C)}\right) = S_C S_{P(C)}. \tag{0.5}$$

The CJS survival estimator is negatively biased for survival of control fish if there is PIT-tag loss or failure after release.

The estimator for the CJS survival parameter for the treatment group is

$$\hat{S}_{CJS(T)} = \frac{\left(n_{1(T)} + n_{2(T)}\right)\left(n_{1(T)} + n_{3(T)}\right)}{R_T n_{1(T)}}, \tag{0.6}$$

with expected value

$$E\left(\hat{S}_{CJS(T)}\right) = S_T. \tag{0.7}$$

The CJS survival estimator is unbiased for survival of treatment fish in the presence of PIT-tag loss, as long as PIT-tag and acoustic-tag detections are used at different sites and PIT-tag loss occurs independently of acoustic-tag loss.

The recommended estimator of Δ is

$$\hat{\Delta} = \frac{\hat{S}_{CJS(T)}}{\hat{S}_{CJS(C)}}. \tag{0.8}$$

The numerator of the estimator of Δ in Equation 1.8 is an unbiased estimator of survival of the double-tagged fish to McNary, while the denominator is a negatively biased estimator of survival of single-tagged fish to McNary, with the bias caused by PIT-tag loss or failure among the control group. The expected value of the estimator in Equation 1.8 is approximately

$$E\left(\hat{\Delta}\right) \approx \frac{S_T}{S_C S_{P(C)}} = \Delta \frac{1}{S_{P(C)}}. \tag{0.9}$$

Thus, if there is no PIT-tag loss or failure among the control group between release at Lower Granite and reaching McNary, then Equation 1.8 provides an unbiased estimate of Δ. Otherwise, Equation 1.8 is positively biased, and the effect of PIT-tag loss on the estimate of Δ may be explored for different hypotheses about tag loss or failure among the control group.

Conclusions

In order to estimate fish survival from release to McNary (first detection site) for double-tagged fish, we recommend using the CJS model to analyze detection histories composed of PIT-tag detections at McNary and acoustic-tag detections pooled across acoustic arrays downstream of McNary. This approach yields a survival estimator that is unbiased and has greater precision than an estimator based on PIT-tag data alone. Using the CJS model to analyze detection histories composed only of PIT-tag data yields a survival estimator that is negatively biased in the case of PIT-tag loss or failure after release. Thus, estimates of the relative survival of acoustic-tagged fish (i.e., double-tagged fish) compared to PIT-tagged fish (i.e., single-tagged fish) will be positively biased if there is tag loss or failure among the single-tagged fish.

References

Cormack, R. M. 1964. Estimates of survival from the sightings of marked animals. Biometrika 51:429-438.

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration - stochastic model. Biometrika 52:225-247.

Seber, G. A. F. 1965. A note on the multiple recapture census. Biometrika 52:249-259.

Appendix

Here, the two-reach CJS model is parameterized and the expected value of the typical CJS survival estimator analyzed for three scenarios: PIT-tag data alone without tag loss, PIT-tag data alone in the presence of tag loss, and PIT-tag data combined with acoustic-tag data in the presence of tag loss. Define the following parameters:

$S_1 =$ survival (of fish) from release to the first detection site;

$S_{P1} =$ the probability that the PIT tag remains implanted and operational from release to the first detection site, i.e., "survival" of the PIT tag;

$p_1 =$ the conditional probability of PIT-tag detection at the first detection site, given reaching that site with a functioning PIT tag;

$\lambda =$ the joint probability of (fish) survival from the first detection site to the second detection site and being detected at the second site, conditional on reaching the first site;

$\lambda_P =$ the joint probability of fish survival and PIT-tag survival from the first detection site to the second detection site and PIT-tag detection at the second site, conditional on reaching the first site with a functioning PIT tag;

$\lambda_A =$ the joint probability of fish survival and acoustic-tag survival from the first detection site to the second detection site and acoustic-tag detection at the second site, conditional on reaching the first site.

Define the following statistics:

$n_1 =$ number of fish detected at both the first and second detection sites;

$n_2 =$ number of fish detected at the first detection site but not the second;

$n_3 =$ number of fish detected at the second detection site but not the first;

$n_4 =$ number of fish released but not detected at either detection site.

The estimator of the CJS survival parameter (S_{CJS}) is the following:

$$\hat{S}_{CJS} = \frac{(n_1 + n_2)(n_1 + n_3)}{Rn_1}, \qquad (0.10)$$

where R is the size of the release group.

Table A1 shows the possible detection histories and their probabilities in the absence of PIT-tag loss when only PIT-tag detections are used. For this scenario, the expected value of the CJS survival estimator is simply S_1.

Table A1. Possible detection histories and their probabilities using only PIT-tag detections when there is no tag loss.

Detection History Counts	Detection at MCN (PIT)	Detection Downstream (PIT)	Probability
n_1	1	1	$S_1 p_1 \lambda$
n_2	1	0	$S_1 p_1 (1-\lambda)$
n_3	0	1	$S_1 (1-p_1)\lambda$
n_4	0	0	$1 - S_1 + S_1 (1-p_1)(1-\lambda)$

Table A2 shows the possible detection histories and their probabilities in the presence of PIT-tag loss when only PIT-tag detections are used. For this scenario, the expected value of the CJS survival estimator is $S_1 S_{P1}$, the joint probability of reaching the first detection site and having a functioning PIT tag. Thus, the CJS survival estimator is negatively biased for fish survival.

Table A2. Possible detection histories and their probabilities in the presence of tag loss using only PIT-tag detections. S_{P1} is PIT-tag survival to the first site, and λ_P is the joint probability of fish survival and PIT-tag survival from the first site to the second site, given reaching the first site with a functioning PIT tag, and PIT-tag detection at the second site.

Detection History Counts	Detection at MCN (PIT)	Detection Downstream (PIT)	Probability
n_1	1	1	$S_1 S_{P1} p_1 \lambda_P$
n_2	1	0	$S_1 S_{P1} p_1 (1-\lambda_P)$
n_3	0	1	$S_1 S_{P1} (1-p_1) \lambda_P$
n_4	0	0	$1 - S_1 S_{P1} + S_1 S_{P1} (1-p_1)(1-\lambda_P)$

Table A3 shows the possible detection histories and their probabilities when both PIT-tag detections and acoustic-tag detections are used from double-tagged fish in the presence of both PIT-tag loss and acoustic-tag loss, and under the assumption that PIT-tag loss occurs independently of acoustic-tag loss. For this scenario, the expected value of the CJS survival estimator is S_1.

Table A3. Possible detection histories and their probabilities in the presence of tag loss using PIT-tag detections at the first site and acoustic-tag detections at the second site (or pooled downstream sites). PIT-tag loss is assumed to occur independently of acoustic-tag loss. S_{P1} is PIT-tag survival to the first site, and λ_A is the joint probability of fish survival from the first site to the second site (given reaching the first site), acoustic-tag survival from release to the second site, and acoustic-tag detection at the second site.

Detection History Counts	Detection at MCN (PIT)	Detection Downstream (Acoustic)	Probability
n_1	1	1	$S_1 S_{P1} p_1 \lambda_A$
n_2	1	0	$S_1 S_{P1} p_1 (1-\lambda_A)$
n_3	0	1	$S_1 (1-S_{P1} p_1) \lambda_A$
n_4	0	0	$1 - S_1 + S_1 (1-S_{P1} p_1)(1-\lambda_A)$

APPENDIX D

PIT-Tag Detection History Summaries

Appendix Table D1. Location passive integrated transponder (PIT) tag monitors used to estimate detection probability and survival of acoustic vs. PIT-tagged yearling and subyearling Chinook salmon released at Lower Granite Dam, 2007.

PIT detection sites		
Abbreviation	Description	Location (rkm)
GOJ	Little Goose Dam	635
LMJ	Lower Monumental juvenile facility	589
ICH	Ice Harbor Dam	538
MCJ	McNary Dam	470
JDJ	John Day juvenile facility	347
BON	Bonneville Dam	235
TWX	Trawl experimental towed detection system	61-83 (75)

Appendix Table D2. Percentages of hatchery yearling Chinook salmon implanted with both an acoustic transmitter and PIT tag (AT fish) and released into the tailrace of Lower Granite Dam that were detected at PIT-tag detection sites at hydroelectric dams on the Snake and Columbia Rivers, 2007. Numbers of detections are shown in parentheses.

Release date	Number released	Proportion (%) and number detected (n)					
		Little Goose	Lower Monumental	Ice Harbor	McNary	John Day	Bonneville
25 Apr	404	13 (53)	15 (62)	4 (17)	26 (105)	25 (102)	7 (29)
26 Apr	397	14 (57)	14 (55)	7(26)	25 (101)	28 (110)	6 (24)
28 Apr	404	18 (71)	13 (54)	5 (21)	25 (101)	29 (118)	8 (34)
1 May	403	21 (85)	12 (48)	5 (19)	25 (102)	22 (89)	5 (22)
3 May	406	13 (53)	6 (23)	4 (18)	21 (85)	20 (83)	7 (27)
5 May	412	9 (37)	16 (64)	10 (43)	24 (98)	22 (92)	8 (33)
9 May	414	22 (90)	27 (110)	4 (17)	23 (96)	23 (95)	6 (24)
10 May	299	27 (81)	20 (59)	4 (13)	26 (78)	18 (54)	4 (11)
12 May	311	26 (80)	9 (29)	4 (11)	24 (75)	18 (57)	4 (13)
15 May	368	22 (81)	15 (55)	2 (9)	29 (107)	22 (80)	6 (22)
Total	3,818	18 (688)	15 (559)	5 (194)	25 (948)	23 (880)	6 (239)

Appendix Table D3. Percentages of hatchery yearling Chinook salmon implanted only with a PIT tag and released into the tailrace of Lower Granite Dam that were detected at PIT-tag detection sites at hydroelectric dams on the Snake and Columbia Rivers, 2007. Numbers of detections are shown in parentheses.

Release date	Number released	Proportion (%) and number detected (n)					
		Little Goose	Lower Monumental	Ice Harbor	McNary	John Day	Bonneville
24 Apr	4,512	9 (425)	13 (609)	6 (260)	34 (1,514)	32 (1,422)	9 (392)
26 Apr	3,769	12 (440)	14 (538)	6 (212)	31 (1,157)	31 (1,162)	9 (322)
28 Apr	3,334	16 (540)	16 (518)	5 (156)	28 (950)	30 (990)	7 (243)
1 May	3,792	18 (664)	10 (365)	3 (132)	30 (1,128)	30 (1,132)	11 (315)
3 May	8,040	11 (857)	3 (265)	3 (251)	27 (2,193)	26 (2,102)	9 (729)
5 May	5,579	8 (461)	11 (638)	7 (417)	26 (1,471)	26 (1,462)	9 (491)
8 May	3,561	18 (658)	27 (965)	4 (141)	25 (878)	25 (880)	8 (302)
10 May	4,773	28 (1,321)	23 (1,093)	4 (197)	30 (1,364)	27 (1,221)	8 (340)
12 May	4,804	22 (1,078)	9 (419)	5 (234)	30 (1,454)	27 (1,319)	8 (385)
15 May	4,550	16 (738)	15 (680)	2 (89)	30 (1,363)	22 (1,021)	6 (284)
Total	46,714	15 (7,182)	13 (6,090)	4 (2,089)	29 (13,472)	27 (12,711)	8 (3,803)

Appendix Table D4. Percentages of AT pilot (85-94 mm) hatchery subyearling Chinook salmon implanted with an acoustic transmitter and a PIT tag and released into the tailrace of Lower Granite Dam that were detected at PIT-tag detection sites at hydroelectric dams on the Snake and Columbia Rivers, 2007. Numbers of detections are shown in parentheses.

Release date	Number released	Proportion (%) and number detected (n)					
		Little Goose	Lower Monumental	Ice Harbor	McNary	John Day	Bonneville
5 June	90	29 (26)	2 (2)	0 (0)	3 (3)	1 (1)	0 (0)
6 June	87	26 (23)	5 (4)	1 (1)	2 (2)	2 (2)	0 (0)
7 June	91	31 (28)	1 (1)	0 (0)	3 (3)	0 (0)	0 (0)
8 June	89	20 (18)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)
9 June	81	25 (20)	0 (0)	2 (2)	1 (1)	0 (0)	0 (0)
12 June	89	31 (28)	3 (3)	2 (2)	3 (3)	0 (0)	0 (0)
13 June	92	26 (24)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)
14 June	113	28 (32)	2 (2)	1 (1)	2 (2)	1 (1)	0 (0)
15 June	103	25 (26)	0 (0)	1 (1)	1 (1)	0 (0)	0 (0)
16 June	127	29 (37)	0 (0)	2 (2)	1 (1)	2 (2)	2 (2)
19 June	104	13 (13)	1 (1)	1 (1)	0 (0)	0 (0)	0 (0)
20 June	106	15 (16)	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)
21 June	97	24 (23)	2 (2)	1 (1)	0 (0)	0 (0)	0 (0)
22 June	89	10 (9)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)
23 June	108	16 (17)	1 (1)	1 (1)	1 (1)	0 (0)	0 (0)
26 June	79	19 (15)	0 (0)	0 (0)	1 (1)	2 (2)	1 (1)
27 June	98	10 (10)	1 (1)	0 (0)	1 (1)	0 (0)	0 (0)
28 June	116	13 (15)	2 (2)	0 (0)	1 (1)	0 (0)	0 (0)
29 June	71	13 (9)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)
30 June	59	14 (8)	3 (2)	0 (0)	0 (0)	0 (0)	2 (1)
3 July	40	0 (0)	0 (0)	0 (0)	3 (1)	0 (0)	0 (0)
4 July	84	20 (17)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
5 July	53	8 (4)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
6 July	4	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
12 July	2	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
13 July	13	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
14 July	12	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Total	2,097	20 (418)	1 (24)	1 (12)	1 (22)	<1 (9)	<1 (4)

Appendix Table D5. Percentages of AT (> 94 mm) hatchery subyearling Chinook salmon implanted with an acoustic transmitter and a PIT tag and released into the tailrace of Lower Granite Dam that were detected at PIT-tag detection sites at hydroelectric dams on the Snake and Columbia Rivers, 2007. Numbers of detections are shown in parentheses.

Release date	Number released	Proportion (%) and number (n) detected					
		Little Goose	Lower Monumental	Ice Harbor	McNary	John Day	Bonneville
5 June	260	19 (50)	6 (15)	2 (5)	21 (54)	5 (13)	4 (10)
6 June	267	23 (62)	6 (15)	2 (6)	14 (38)	5 (13)	2 (6)
7 June	263	29 (77)	5 (13)	2 (6)	11 (30)	6 (17)	2 (6)
8 June	263	25 (65)	5 (14)	2 (4)	5 (14)	2 (5)	<1 (1)
9 June	271	25 (68)	1 (4)	1 (4)	9 (24)	4 (10)	1 (3)
12 June	261	34 (89)	3 (7)	1 (2)	5 (13)	4 (11)	2 (4)
13 June	270	26 (69)	0 (0)	1 (4)	4 (12)	2 (5)	1 (2)
14 June	308	23 (71)	1 (3)	2 (6)	4 (13)	1 (4)	2 (6)
15 June	323	25 (82)	1 (3)	1 (2)	5 (16)	2 (5)	1 (2)
16 June	270	21 (57)	2 (5)	1 (4)	6 (15)	1 (3)	1 (4)
19 June	328	18 (60)	1 (4)	2 (7)	9 (28)	2 (6)	2 (5)
20 June	247	14 (34)	2 (5)	1 (2)	5 (13)	1 (3)	1 (2)
21 June	273	13 (35)	2 (5)	1 (4)	4 (10)	1 (4)	2 (5)
22 June	320	16 (50)	2 (7)	0 (1)	9 (28)	3 (8)	1 (4)
23 June	302	14 (41)	2 (5)	1 (2)	6 (18)	2 (7)	1 (4)
26 June	337	17 (56)	3 (9)	2 (6)	5 (16)	1 (3)	<1 (1)
27 June	246	15 (37)	2 (4)	1 (2)	5 (13)	2 (5)	<1 (1)
28 June	270	13 (34)	1 (3)	<1 (1)	3 (8)	1 (3)	<1 (1)
29 June	243	17 (42)	1 (3)	1 (2)	3 (7)	1 (3)	1 (2)
30 June	290	19 (54)	2 (7)	2 (6)	2 (7)	1 (4)	0 (0)
3 July	271	21 (56)	3 (7)	1 (3)	2 (6)	1 (3)	1 (2)
4 July	292	21 (62)	2 (6)	< 1 (1)	2 (5)	1 (4)	< 1 (1)
5 July	237	17 (41)	< 1 (1)	< 1 (1)	1 (3)	< 1 (1)	< 1 (1)
6 July	137	20 (28)	1 (2)	1 (2)	1 (1)	0 (0)	0 (0)
12 July	549	8 (43)	1 (6)	1 (3)	< 1 (2)	1 (3)	0 (0)
13 July	329	4 (13)	0 (0)	0 (0)	< 1 (1)	< 1 (1)	0 (0)
14 July	309	4 (13)	0 (0)	0 (0)	0 (0)	0 (0)	< 1 (1)
Total	7,736	18 (1,389)	2 (153)	1 (86)	5 (395)	2 (144)	1 (74)

Appendix Table D6. Percentages of hatchery subyearling Chinook salmon implanted only with a PIT tag and released into the tailrace of Lower Granite Dam that were detected downstream at dams or in the estuary trawl detection system, 2007. Numbers of detections are shown in parentheses.

Release date	Number released	Detections (%) of hatchery subyearling Chinook salmon (n)						
		Little Goose	L. Monumental	Ice Harbor	McNary	John Day	Bonneville	Estuary Trawl
5 June	1,096	16 (176)	4 (45)	4 (41)	23 (253)	12 (134)	9 (99)	1 (8)
6 June	1,171	21 (245)	5 (55)	2 (18)	26 (307)	11 (125)	7 (81)	1 (9)
7 June	1,131	22 (249)	5 (52)	2 (24)	23 (257)	11 (122)	7 (78)	1 (6)
8 June	1,081	22 (237)	4 (39)	2 (22)	18 (192)	11 (116)	7 (78)	1 (10)
9 June	1,133	23 (266)	2 (26)	1 (16)	15 (174)	10 (108)	7 (79)	1 (10)
12 June	1,070	20 (215)	2 (18)	1 (10)	12 (131)	6 (63)	5 (55)	< 1 (4)
13 June	1,143	24 (276)	1 (11)	1 (13)	12 (137)	7 (85)	6 (71)	1 (13)
14 June	1,075	22 (236)	1 (10)	1 (11)	12 (128)	6 (65)	6 (60)	< 1 (5)
15 June	895	21 (189)	1 (10)	1 (11)	10 (93)	8 (70)	5 (45)	< 1 (4)
16 June	1,240	19 (238)	1 (12)	1 (8)	11 (139)	7 (88)	4 (54)	1 (7)
19 June	1,225	17 (211)	1 (10)	1 (12)	12 (146)	5 (59)	6 (70)	1 (7)
20 June	906	13 (116)	< 1 (4)	1 (9)	10 (93)	5 (43)	5 (48)	0 (0)
21-Jun	834	13 (107)	1 (12)	< 1 (4)	10 (86)	5 (44)	7 (59)	< 1 (8)
22-Jun	759	10 (78)	2 (17)	1 (10)	11 (85)	4 (32)	5 (38)	1 (9)
23 June	1,002	10 (99)	1 (9)	1 (14)	10 (96)	5 (54)	6 (62)	1 (6)
26 June	1,412	16 (221)	2 (25)	1 (19)	13 (182)	4 (62)	5 (64)	< 1 (7)
27 June	1,154	14 (167)	1 (15)	1 (15)	12 (134)	5 (55)	4 (44)	1 (9)
28 June	973	16 (155)	2 (22)	2 (16)	12 (112)	4 (40)	4 (41)	< 1 (2)
29 June	386	16 (62)	3 (13)	3 (10)	12 (45)	4 (17)	5 (18)	1 (2)
30 June	616	18 (108)	2 (13)	3 (20)	11 (66)	5 (32)	4 (24)	< 1 (1)
3 July	1,089	19 (202)	2 (24)	1 (15)	7 (71)	4 (40)	3 (29)	< 1 (2)
4 July	649	26 (168)	3 (22)	2 (13)	7 (47)	5 (33)	4 (25)	0 (0)
5 July	605	19 (114)	3 (17)	1 (7)	5 (30)	3 (21)	3 (18)	0 (0)
6 July	1,448	22 (316)	4 (52)	2 (23)	7 (98)	4 (53)	2 (30)	0 (0)
11 July	274	14 (38)	1 (4)	0 (0)	1 (4)	2 (6)	1 (4)	0 (0)
12 July	771	16 (121)	1 (9)	1 (5)	1 (11)	2 (13)	1 (6)	0 (0)
13 July	433	11 (48)	1 (6)	< 1 (1)	2 (7)	1 (6)	0 (0)	0 (0)
14 July	767	13 (98)	1 (11)	1 (4)	2 (13)	2 (15)	< 1 (3)	0 (0)
Overall	26,338	18 (4,677)	2 (563)	1 (371)	12 (3,137)	6 (1,601)	5 (1,283)	< 1 (129)

APPENDIX E: Histological Metrics

Appendix Table E. Description of metrics used in histological evaluations. Except where otherwise noted, all metrics are evaluated by presence/absence.

Metric	Description/biological meaning
Liver	
Liver vacuolation	Measure of the normal glycogen (energy) or lipid/fat stores in liver; primarily glycogen. This is a nutritional measure. Measured on ordinal scale of 1-7.
Liver lymphocytic infiltrates and PV cuffing	Can be an indicator of BKD.
Liver hydropic vacuolation (abbr. Liver HYDVAC):	Water vacuoles in the liver cell. Occurrence may be related to previous exposure to chlorinated hydrocarbons (marine fish) or changes in pH.
Liver coagulative necrosis:	Coagulative necrosis in hepatocytes of liver
Liver eosinophilic hypertrophy (abbr. Liver eosin. Hypertrophy):	Phenomena where hepatocytes stain more eosinophilic than usual, and are hypertrophied; occurrence is often related to degenerative changes.
Liver BKD lesions:	Lesions suggestive of bacterial kidney disease in liver.
Liver Ceratomyxa lesions:	Ceratomyxa shasta-like myxosporeans in liver.
Pancreas	
Pancreatic zymogen	A digestive enzyme measured on an ordinal scale of 0-3. Low or absent pancreatic zymogen indicates that a fish has stopped eating.
Pancreatic atrophy	Evidence that pancreatic cells have shrunk. This metric also indicates that a fish has stopped eating.
Pancreatic Inflammation	Inflammatory cell infiltrates in and around the exocrine pancreas.
Stomach	
Pyloric caecae mucosal glycogen	Glycogen reserves in the pyloric caecae; rated on an ordinal scale from 0-3.
Small intestine	
Small intestinal mucosal glycogen	Glycogen reserves in the small intestine. This is generally not a good indicator or nutritional status; rated on an ordinal scale from 0-3.
Small intenstinal digesta	Presence/absence of food in the small intestine. This metric is a nutritional measure.
Small intestinal trematode content	When present, small intestinal trematodes appeared to be at commensal levels.
Small intestinal inflammation	Prevalence of intestinal inflammation.
Small intestinal Ceratomyxa	Organisms resembling Ceratomyxa shasta in mucosa of small intestine.
Lower intestine	
Lower intestinal mucosal glycogen levels	Glycogen stores in the lower intestine; rated on an ordinal scale from 0-3. This metric is a nutritional indicator.
Lower intestinal digesta	Presence/absence of food in the large intestine. This metric is a nutritional measure.
Lower intestinal trematodes	If present, levels did not appear higher than normal, and there was no indication that trematodes were causing problems for these fish.
Lower intestinal inflammation	Inflammation in the lower intestine.

Appendix Table E. Continued.

Metric	Description/biological meaning
Heart epicarditis/myocarditis	Either inflammation of the epicardium (epicarditis) or myocardium (myocarditis) in the heart.
Kidney	
Kidney BKD lesions	Indication of BKD response.
Kidney tubule epithelial necrosis	Coagulative necrosis of the epithelium lining the tubules of the kidney nephrons.
Kidney tubule Myxosporea	Unidentified myxosporean infection of the epithelium lining the kidney tubules.
Kidney tubule hydropic vacuolation	Water vacuoles in the kidney tubule cells.
Spleen	
Splenic congestion	Typically indicates a generalized response to stress.
Splenic macrophage aggregates	Normal structures, indicating activity of reticuloendothelial system; rated on ordinal scale from 1-7.
Spleen lymphoid depletion	Reduction in normal proportion of white pulp (lymphoid tissue) to red pump (erythropoietic tissue) in the spleen.
Peritoneum	
Mesenteric chronic inflammation	Inflammation in mesentery; presence probably does not effect mortality; rated as presence/absence.
Mesenteric chronic inflammation severity	Inflammation in mesentery; presence probably does not effect mortality; rated on an ordinal scale from 0-7.
Mesenteric adipose content	Fat reserves in the mesentery; measured on an ordinal scale from 0-3. This metric is a nutritional measure.
Peritonitis, chronic	Internal adhesions at the site of the incision. When present, there were no obvious signs of an infectious cause such as the presence of large amounts of bacteria; however, an infectious cause could not be ruled out.
Wound healing	
Incision closure	Describes whether or not the incision appears closed over by epidermal cells; 1= closure, 0 = open, no closure.
Skin stratum compactum reknitting	Reknitting or reconnection of the stratum compactum layer in the dermis, where the stratum compactum layer on either side of surgical incision has joined together.
Incision, poor apposition	This parameter shows whether or not there was a poor, uneven apposition between the two sides of the incision; essentially describes poor or uneven (i.e. overlapping, rather than evenly apposed) closure of the two body wall surfaces by the sutures. Poor apposition creates a larger entry point for secondary pathogens to enter the wound site and the peritoneal cavity: 1 = poor 0 = good
Incision, chronic inflammation	Measure of presence/absence of chronic inflammatory infiltrates (e.g. macrophages, lymphocytes) at the incision site.
Incision, chronic inflammation severity	Ordinal measure (0-7) of degree of cellular infiltrates in region of incision, as above.
Dermal musculature necrosis	Measure of residual muscle necrosis at incision site.
Dermal hemorrhage fibrin	Measure of residual hemorrhage or fibrin deposition in area of incision.
Incision adhesions	Adhesions between mesenteries associated with internal organs and the peritoneum in the area of the incision and suture site. Adhesions are usually associated with chronic peritonitis.
Internal organ evulsion through incision and presence of saprolegnia	Evaluated internally and externally; measured as presence/absence.

APPENDIX F

Covariate Analysis of Factors Affecting Survival

Methods

Bivariate and multivariable regression analyses were used to identify factors associated with all observed tag effects. Tag effect was defined as a significant ($\alpha = 0.05$) difference in the mean survival probability between acoustic- and PIT-tagged fish within a release group at a detection site. Relative survival (i.e., mean AT survival probability / mean PIT survival probability) was used as the response variable in the regression models as a measure of tag effect. A relative survival value greater than or equal to one indicated no tag effect because AT fish survived as well as, or better than PIT-tagged fish. A relative survival value of less than one indicated AT fish had a lower probability of survival than PIT-tagged fish. Predictor variables included in the regression models included mean river discharge (kcfs), mean water temperature (°C), release date (ordinal day of year), mean tag burden (%; calculated from weight obtained at tagging), mean Fulton's condition factor (C; calculated from length and weight obtained at tagging), mean fork length (mm; measured at tagging), and median travel rate (km/d).

Using methods similar to those described by Berggren and Filardo (1993) the river discharge and water temperature variables were calculated as averages of their daily averages over the estimated median travel times (i.e., the mean river discharge and mean water temperature experienced by the first 50% of each release group to arrive at each detection site was calculated from daily averages), which were obtained from the Columbia River Data Access in Real Time website (www.cbr.washington.edu/dart). For example, AT fish released into the tailrace of Lower Granite Dam on 24 April had a median travel time of 6 d to Little Goose Dam. The mean river discharge and water temperature experienced by the first 50% of this release group to arrive at Little Goose Dam was calculated from the daily averages of river discharge and water temperature recorded at Little Goose Dam during the 24-30 April period. The use of this method for estimating mean river discharge and mean water temperature ensured that the conditions experienced by the leading half of a release group (up to the arrival of the median fish) were taken into account (Berggren and Filardo 1993).

Time-related factors, such as differences in the physiological development of release groups (Giorgi et al. 1997; Smith et al. 2003) and differing day lengths (Berggren and Filardo 1993), may affect the survival of juvenile Chinook salmon. These factors were addressed in the models by including the ordinal day of year (i.e., 1-365) that fish were released into the tailrace of Lower Granite Dam as a variable.

Tag burden was included as a variable in the models because adverse effects on fish physiology and behavior can increase as the ratio of transmitter weight to fish weight increases (Marty and Summerfelt 1986; Greenstreet and Morgan 1989). Additionally, the physical state of a fish at the time of transmitter implantation may affect its reaction to the transmitter and ultimately its probability of survival. Therefore, Fulton's condition factor:

$$C = (W/L^3) \times 100{,}000$$

where W = weight (g), and L = fork length (mm) was also included in the model. Fork length was included as a variable in the models to determine the effects of implanting fish of various lengths on the survival of acoustic-tagged fish. Mean tag burden, condition factor, and fork length were calculated from all acoustic-tagged fish that were released in each group.

The amount of time taken by fish to travel through the CRB can affect their probability of survival. Fish that take longer to travel through the system may experience greater exposure time to predators, parasites, bacteria, and potentially unfavorable water conditions. Therefore, median travel rate from release at Lower Granite Dam to each downstream PIT tag detection site was calculated for each release group of acoustic-tagged fish and included as a predictor variable in the regression models. Travel rate was used as a response variable instead of travel time to allow for comparisons between reaches of different lengths.

Six regression models (one for each detection site) were possible for both yearling and subyearling AT fish. However, ten or greater AT fish from each release group had to be detected at a PIT detection site to provide reliable estimates of travel rate, river discharge, and water temperature. If fewer than ten AT fish from a release group were detected at a detection site, that group of fish was removed from the regression analyses developed for that detection site. Additionally, regression analyses were not conducted for a detection site if fewer than ten AT fish were detected at that detection site from more than half of the release groups.

The goal of conducting these analyses was to create multivariable models that had minimal multicollinearity among predictor variables, high R^2 values, and meaningful interpretation of the variables retained in the final model. First, bivariate regression models were developed by fitting each predictor variable to the response variable (relative survival) to determine the strength and direction of relationships. Next, all possible combinations of variables were regressed against relative survival to find the multivariable model that best fit the aforementioned criteria. Problematic multicollinearity in the multivariable models was identified by sign changes of regression coefficients (b) that were significantly ($\alpha = 0.05$) correlated with relative survival in the bivariate regression analysis and from strong correlations among predictor variables, which were obtained by calculating Pearson correlation coefficients (r). Models with problematic multicollinearity or nonsignificant ($P > 0.05$) regression coefficients were removed from further analysis. The remaining model with the highest predictive potential, based on the coefficient of determination (R^2), was retained.

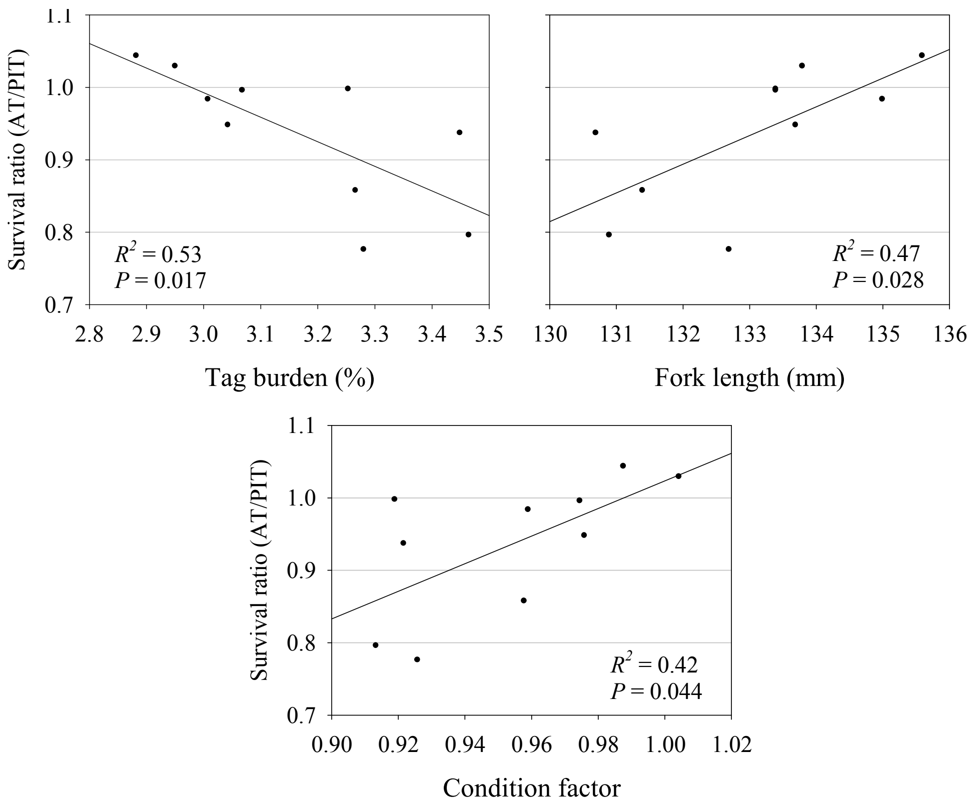
Results

Yearling Chinook Salmon—Bivariate and multivariable regression analyses were conducted on the AT/PIT survival ratio for each reach (i.e., release to dam) where a significant tag effect was observed. Thus, regression analyses were conducted using all release groups for the reaches from release to John Day and Bonneville Dams. Regression analyses were also conducted for the reach from release to McNary Dam, as the difference in survival between acoustic- and PIT-tagged fish in this reach approached significance ($P = 0.054$).

Tag burden, fork length, and condition factor were significantly ($\alpha = 0.05$) correlated with AT/PIT survival ratio in the bivariate analyses for AT yearling Chinook salmon migrating to McNary Dam (Appendix Table F1). Tag burden was negatively correlated with and explained 53% of the variation in the survival ratio (Appendix Figure F1). Fork length and condition factor were positively correlated with and accounted for 47% and 42% of the variation in survival ratio, respectively (Appendix Figure F1). The significant ($P = 0.017$) multivariable model included fork length, water temperature, and river discharge and explained 80% of the variation in the survival ratio (Appendix Table F2). However, strong correlations among predictor variables make interpretation of the multivariable model difficult (Appendix Table F3). Tag burden was highly correlated ($r \geq 0.80$) with release day, water temperature, fork length, and condition factor, and condition factor was highly correlated with release day and water temperature (Appendix Table F3).

Appendix Table F1. Results of bivariate analyses of the AT/PIT survival ratio for acoustic-tagged (AT) yearling Chinook salmon migrating from release into the Lower Granite Dam tailrace to McNary Dam in 2007.

Variable	P-value	R^2	Direction of relationship
Tag burden	0.017	0.53	–
Fork length	0.028	0.47	+
Condition factor	0.044	0.42	+
Water temperature	0.107	0.29	+
Release day	0.163	0.23	+
Travel rate	0.514	0.06	+
River discharge	0.734	0.02	+



Appendix Figure F1. Bivariate relationships between AT/PIT survival ratio and tag burden, fork length, and condition factor for acoustic-tagged (AT) yearling Chinook salmon migrating from Lower Granite Dam to McNary Dam in 2007.

Appendix Table F2. Significant multivariable regression model for predicting the AT/PIT survival ratio of acoustic-tagged yearling Chinook salmon migrating from Lower Granite Dam to McNary Dam in 2007.

Variable	Regression Coefficient (*b*)	SE	*t*-value (b = 0)	Probability[b] (b = 0)	R^2	*P*
Constant	-3.92	1.85	-2.12	0.078	0.80	0.017
Fork length	0.05	0.02	2.96	0.026		
Water temperature	0.07	0.03	1.98	0.095		
River discharge	-0.01	< 0.01	-3.07	0.022		

Appendix Table F3. Pearson correlation coefficients (r) among predictor variables included in the multivariable regression analysis to determine the factors associated with the AT/PIT survival ratio of acoustic-tagged (AT) yearling Chinook salmon migrating from Lower Granite Dam to McNary Dam in 2007.

Variable	Release day	River discharge	Water temperature	Travel rate	Fork length	Tag burden	Condition factor
Release day	1.00	0.79	0.99	0.86	0.70	-0.83	0.82
River discharge	0.79	1.00	0.77	0.88	0.66	-0.62	0.47
Water temperature	0.99	0.77	1.00	0.83	0.73	-0.87	0.86
Travel rate	0.86	0.88	0.83	1.00	0.57	-0.59	0.50
Fork length	0.70	0.66	0.73	0.57	1.00	-0.92	0.65
Tag burden	-0.83	-0.62	-0.87	-0.59	-0.92	1.00	-0.90
Condition factor	0.82	0.47	0.86	0.50	0.65	-0.90	1.00

No predictor variables were significantly (α = 0.05) correlated in the bivariate analyses with the AT/PIT survival ratio for acoustic-tagged yearling Chinook salmon migrating from release into the Lower Granite Dam tailrace to John Day Dam (Appendix Table F4). The significant (P = 0.003) multivariable model, including tag burden and river discharge, explained the most variation (80%) in survival ratio among all possible models (Appendix Table F5). However, direct interpretation of the multivariable model is convoluted because tag burden was highly correlated ($r \geq 0.80$) with release day, water temperature, fork length, and condition factor (Appendix Table F6).

Appendix Table F4. Results of bivariate analyses of the AT/PIT survival ratio for acoustic-tagged (AT) yearling Chinook salmon migrating from Lower Granite Dam to John Day Dam in 2007.

Variable	*P*-value	R^2	Direction of relationship
Condition factor	0.080	0.33	+
Tag burden	0.120	0.28	–
River discharge	0.190	0.20	–
Fork length	0.248	0.16	+
Water temperature	0.400	0.09	+
Release day	0.454	0.07	+
Travel rate	0.981	< 0.01	+

Appendix Table F5. Significant multivariable regression model for predicting the AT/PIT survival ratio of acoustic-tagged (AT) yearling Chinook salmon migrating from Lower Granite Dam to John Day Dam in 2007.

Variable	Regression coefficient (*b*)	SE	*t*-value ($b = 0$)	Probability[b] ($b = 0$)	R^2	*P*
Constant	6.65	1.13	5.86	< 0.001	0.80	0.003
Tag burden	-0.60	0.13	-4.60	0.002		
River discharge	-0.02	< 0.01	-4.32	0.003		

Appendix Table F6. Pearson correlation coefficients (*r*) among predictor variables included in the multivariable regression analysis to determine the factors associated with the AT/PIT survival ratio of acoustic-tagged (AT) yearling Chinook salmon migrating from Lower Granite Dam to John Day Dam in 2007.

Variable	Release day	River discharge (kcfs?)	Water temp. (°C)	Travel rate	Fork length (mm)	Tag burden (% body wt)	Condition factor
Release day	1.00	0.58	1.00	0.90	0.70	-0.83	0.82
River discharge	0.58	1.00	0.55	0.74	0.52	-0.41	0.19
Water temperature	1.00	0.55	1.00	0.88	0.72	-0.85	0.84
Travel rate	0.90	0.74	0.88	1.00	0.62	-0.66	0.59
Fork length	0.70	0.52	0.72	0.62	1.00	-0.92	0.65
Tag burden	-0.83	-0.41	-0.85	-0.66	-0.92	1.00	-0.90
Condition factor	0.82	0.19	0.84	0.59	0.65	-0.90	1.00

No predictor variables were significantly ($\alpha = 0.05$) correlated in the bivariate analyses with the AT/PIT survival ratio for acoustic-tagged yearling Chinook salmon migrating to Bonneville Dam (Appendix Table F7). Each predictor explained less than 20% of the variation in survival ratio (Appendix Table F7). Additionally, no combination of predictor variables resulted in a significant ($\alpha = 0.05$) multivariable model.

Appendix Table F7. Results of bivariate analyses of the AT/PIT survival ratio for acoustic-tagged (AT) yearling Chinook salmon migrating from Lower Granite Dam to Bonneville Dam in 2007.

Variable	*P*-value	R^2	Direction of relationship
Water temperature	0.213	0.19	+
Release day	0.221	0.18	+
Tag burden	0.314	0.13	–
Fork length	0.325	0.12	+
Condition factor	0.380	0.10	+
River discharge	0.662	0.03	–
Travel rate	0.686	0.02	+

Subyearling Chinook Salmon—Condition factor, tag burden, and fork length of AT≥95 mm FL subyearling Chinook salmon migrating to Little Goose Dam were significantly ($\alpha = 0.05$) correlated in the bivariate regression analyses with the AT/PIT survival ratio (Appendix Table F8). Condition factor, tag burden, and fork length explained 22, 21, and 19% of the variation in survival ratio, respectively. However, the direction of all relationships between significant predictor variables and survival ratio was inverse of expected. For example, condition factor and fork length were negatively correlated with survival ratio, and tag burden was positively correlated with survival ratio (Appendix Table F8). Condition factor, tag burden, and fork length were highly correlated ($r > 0.75$) with each other and with release day (Appendix Table F9), which may have caused the anomalous correlations with AT/PIT survival ratio. No combination of predictor variables resulted in a significant ($\alpha = 0.05$) multivariable model.

Appendix Table F8. Results of bivariate analyses of AT/PIT survival ratio for acoustic-tagged (AT≥95 mm FL) subyearling Chinook salmon migrating from Lower Granite Dam to Little Goose Dam in 2007. Variables are ordered by *P*-value.

Variable	*P*-value	R^2	Direction of relationship
Condition factor	0.017	0.22	-
Tag burden	0.021	0.21	+
Fork length	0.028	0.19	-
Release day	0.072	0.13	-
Water temperature	0.138	0.09	-
River discharge	0.304	0.05	+
Travel rate	0.521	0.02	+

Appendix Table F9. Pearson correlation coefficients (*r*) among predictor variables included in the multivariable analysis to determine factors associated with AT/PIT survival ratio of acoustic tagged test (AT≥95 mm FL) river-run subyearling Chinook salmon migrating from Lower Granite Dam to Little Goose Dam in 2007.

Variable	Release day	River discharge	Water temperature	Fork length	Condition factor	Tag burden	Travel rate
Release day	1.00	-0.88	0.94	0.82	0.89	-0.89	0.00
River discharge	-0.88	1.00	-0.71	-0.66	-0.67	0.72	0.23
Water temp.	0.94	-0.71	1.00	0.83	0.84	-0.88	0.22
Fork length	0.82	-0.66	0.83	1.00	0.79	-0.98	0.19
Condition factor	0.89	-0.67	0.84	0.79	1.00	-0.90	0.04
Tag burden	-0.89	0.72	-0.88	-0.98	-0.90	1.00	-0.14
Travel rate	0.00	0.23	0.22	0.19	0.04	-0.14	1.00

No predictor variables for AT≥95 mm FL subyearling Chinook salmon migrating from Lower Granite Dam to McNary Dam were found to be significantly ($\alpha = 0.05$) correlated with the AT/PIT survival ratio in the bivariate regression analysis (Appendix Table F10). The significant multivariable model that best explained variation in survival ratio of acoustic-tagged subyearling Chinook salmon included river discharge and fork length, and explained 35% of variation in survival ratio ($P = 0.048$; Appendix Table F11). The model indicates that survival ratio increases with increasing river discharge and with increasing fork length of AT≥95 mm FL fish. However, fork length was highly correlated with tag burden and discharge was highly correlated with release day and water temperature (Appendix Table F12) making direct interpretation of the model convoluted.

Appendix Table F10. Results of bivariate analyses of AT/PIT survival ratio for acoustic tagged test (AT≥95 mm FL) subyearling Chinook salmon migrating from Lower Granite Dam to McNary Dam in 2007. Variables are ordered by *P*-value.

Variable	*P*-value	R^2	Direction of relationship
Travel rate	0.063	0.21	+
River discharge	0.151	0.13	+
Water temperature	0.256	0.09	-
Fork length	0.313	0.07	+
Release day	0.352	0.06	-
Condition factor	0.453	0.04	-
Tag burden	0.597	0.02	-

Appendix Table F11. Results of multivariable analyses of AT/PIT survival ratio for acoustic tagged test (AT≥95 mm FL) subyearling Chinook salmon migrating from Lower Granite Dam to McNary Dam in 2007.

Variable	Regression coefficient (b)	SE	t-value ($b = 0$)	Probability ($b = 0$)	R^2	P
Constant	-4.07	1.90	-2.15	0.05	0.35	0.048
River discharge	0.00	0.00	2.48	0.03		
Fork length	0.04	0.02	2.18	0.05		

Appendix Table F12. Pearson correlation coefficients (*r*) among predictor variables included in the multivariable analysis to determine factors associated with AT/PIT survival ratio of acoustic tagged (AT≥95 mm FL) river-run subyearling Chinook salmon migrating from Lower Granite Dam to McNary Dam in 2007.

Variable	Release day	River discharge	Water temperature	Travel rate	Fork length	Condition factor	Tag burden
Release day	1.00	-0.95	0.98	-0.04	0.61	0.70	-0.73
River discharge	-0.95	1.00	-0.97	0.33	-0.44	-0.77	0.61
Water temp	0.98	-0.97	1.00	-0.18	0.52	0.72	-0.67
Travel rate	-0.04	0.33	-0.18	1.00	0.49	-0.32	-0.29
Fork length	0.61	-0.44	0.52	0.49	1.00	0.44	-0.95
Condition factor	0.70	-0.77	0.72	-0.32	0.44	1.00	-0.70
Tag burden	-0.73	0.61	-0.67	-0.29	-0.95	-0.70	1.00